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MARYLAND

EASTERN SHORE

WATER PROJECT

State of Maryland

Governor's Science Advisory Council

1992

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Acknowledgements

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EXECUTIVE SUMMARY

The Governor's Science Advisory Council (GSAC) has performed an independent evaluation of information regarding the status of the available fresh water supply on the Eastern Shore of Maryland and projections in the light of future demands. Information from a variety of sources was employed. Principal sources were the U.S. Geological Survey, U.S. Army Corps of Engineers studies, the Maryland Geological Survey,and the Maryland Department of Natural Resources and the Maryland Department of the Environment. Recommendations for actions are also included.

Most of the water used on the Eastern Shore is ground water, withdrawn from generally confined aquifers. Many rural households use shallow wells in surficial water. In some agricultural areas, this water is supplemented with surface water used primarily for irrigation and livestock watering.

On the whole, the groundwater supply on the Eastern Shore appears to be satisfactory at t his time. A vast majority of rural users can be expected to continue to use a safe and ade-quate water supply. Certain problem areas are highlighted in this report. However, DOE emphasized that a potential for groundwater contamination exists throughout the area. Chemical spills, underground tank ruptures, excessive pesticide and fertilizer applications can result in contaminated groundwater and possibly the water supply. Vigilance must be maintained to protect the water supply to include such measures as periodic monitoring, water resource planning and Maryland's Wellhead Protection Program.

Salisbury is the only urban community on the Eastern Shore that is supplied with water from a relatively shallow, unconfined aquifer. This source has the potential of being contaminated more readily than deeper and confined aquifers, and from sources further afield than might typically be the case. The DOE concluded that the City's Well Head Protection Program should continue to address these concerns. It is essential that the regulations governing the purity of this water supply be diligently observed.

The interplay between contamination of the water table aquifer and the resulting increased demand of groundwater from the Piney Point aquifer emphasizes the shared relationship and responsibility between DOE, protecting the quality of the water resources, and DNR, assuring that all users have an adequate supply of potable water.

The proximity of developed areas to both the Atlantic Ocean and the Chesapeake Bay makes high chloride levels in drinking water a continuing issue on the Eastern Shore. While some cases of elevated chloride levels result from natural mixing with brackish surface water, or from improperly abandoned wells that provide a direct conduit to the fresh water aquifers, serious consideration must be given to areas where changes in groundwater result from significant groundwater withdrawal. Two areas of special concern are Kent Island and Ocean City.

Kent Island currently does not have a central water supply, but relies largely on domestic wells. It has been recognized that local excessive salt water intrusion into the Aquia aquifer, which is the principal aquifer furnishing water to Kent Island, has occurred. MGS has used a model, applied to the water supply problem, which assumes both a growth rate in demand and a range of water withdrawal rates. MGS also used a flow model to the area to examine hydrogeological controls. A number of alternate strategies for supplying fresh water to Kent Island were examined.

Since then, the MGS, the Water Resources Administration (WRA) and Queen Anne's County developed a program designed to reduce their principal reliance on the Aquia aquifer by using the deeper Magothy aquifer instead. Recent readings from the chloride monitoring system established by the MGS indicate that chloride levels have stabilized. Water levels in the Magothy aquifer must be monitored to assure that Kent Island withdrawals do not exceed the rate of replenishment.

The most serious threat to the water supply appears to be the Ocean City, Worcester County and Coastal Sussex County (Delaware) area, where considerable economic development, and population growth is expected to continue. The hydrogeology involved is discussed in the report in some detail.

Some wells in Ocean City have already experienced saltwater intrusion. MGS has done additional studies recently to determine the extent of future saltwater intrusion.

DNR has performed a study of the groundwater supply in the area. A number of short range measures were recommended and are generally being implemented to varying degrees. They are principally conservation measures, or redistribution of pumping efforts to relieve pressure on some wells. DNR states that if their measures are fully implemented further saltwater intrusion is not

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On the other hand, **GSAC believes that salt water intrusion into the Ocean City/Sussex County water supply, even with the above measures, highly likely.** This judgement is based on consideration of the forecast growth of the region, the considerable uncertainties regarding the mechanisms by which saltwater intrusion is occurring, as well as the lack of key data, such as the location and movement of the saltwater wedge under the ocean, and the latest MGS data. Longer range measures must be undertaken prior to the point in time when prohibitive saltwater intrusion can be predicted.

A 1985 Corps of Engineers study examined the cost of long range alternatives. The assumptions that form the basis for the study are inadequate and the results are not meaningful. It is essential that an objective engineering cost estimate of the alternatives be conducted to determine the feasibility of employing each of the alternatives.

The aquifers serving Ocean City, the areas west of Assawoman and Sinepuxent Bay, as well as the coastal areas in Delaware are geologically interconnected with the result that they operate almost as a single hydrogeological system. Solutions should, therefore, be based on multi-state approaches.

Many of the highly productive aquifers have recharge areas far removed from the users of that water. Regional planning is, therefore, essential to assure that land use in the recharge areas does not impair the recharge of these aquifers. A key role in the protection of confined aquifers from "leakage" of contaminants from the overlying aquifers, particularly in recharge areas is played by the periodic monitoring system to detect problems and by the Wellhead Protection Program to prevent problems from happening.

Recommendations

In order for the majority of water users on the Eastern Shore to continue to receive an adequate supply of good water, several short and long term actions should be defined:

a. Strict management of the water resources for Salisbury, including the recharge areas, must be maintained.

b. The decline in the water level of the Piney Point aquifer in Caroline County and environs should be carefully monitored and further withdrawals of this aquifer should be restricted accordingly. Contingency plans should be prepared before previous wells run dry.

c. The impact on the Magothy water level, as a result of the implementation of the Kent Island water management strategy should be carefully monitored.

d. The general application of the 80% water level policy to determine adequacy of the water supply should be reexamined to assure that previous updip well owners are not impacted, and that the drawdown is not sufficient to cause saltwater intrusion.

e. The feasibility of using inland wellfields to supplement the Ocean City water supply must be carefully studied in order to prevent upsetting the balance between existing aquifers and the intrusion of salt water into the water supply west of Assawoman Bay.

f. The selection of a strategy to solve the Ocean City, Worcester County and Sussex County water supply is very complex and involves several jurisdictions. It is essential that a master plan be developed in conjunction with all the jurisdictions involved, and that all alternatives be objectively examined. A full economic analysis is required.

Finally, it is essential to consider water as a finite resource. Consequently it is essential that a comprehensive regional strategy for the management of water withdrawals be developed based on the best current water resource and usage data available, as well as based on future expected growth and land use. While many agencies research and maintain data, the trends of this data are not brought to focus in any agency and used for planning and allocation.

INTRODUCTION

The Governor's Science Advisory Council (GSAC) has performed an independent evaluation of available information to determine the status of the available fresh water supply on the Eastern Shore of Maryland and to project consumption in the light of future demands. Recommendations for actions are included.

The Eastern Shore of Maryland is the central portion of the Delmarva Peninsula. The Peninsula extends from the fall line in the north and is bounded by Delaware Bay in the northeast, the Chesapeake Bay in the west and south and the Atlantic Ocean in the east. It comprises more than 6000 square miles within the coastal plain. The land is generally flat and is used primarily for agriculture.

Politically, it contains portions of Delaware to the north, the Eastern Shore of Maryland in the center and portions of Virginia in the south, as shown in Figure 1.

The area is largely agricultural and contains only a few municipalities; Salisbury, Easton, Cambridge and Ocean City. The latter experiences a major seasonal transient population.

The use of water in the Maryland counties of the Eastern

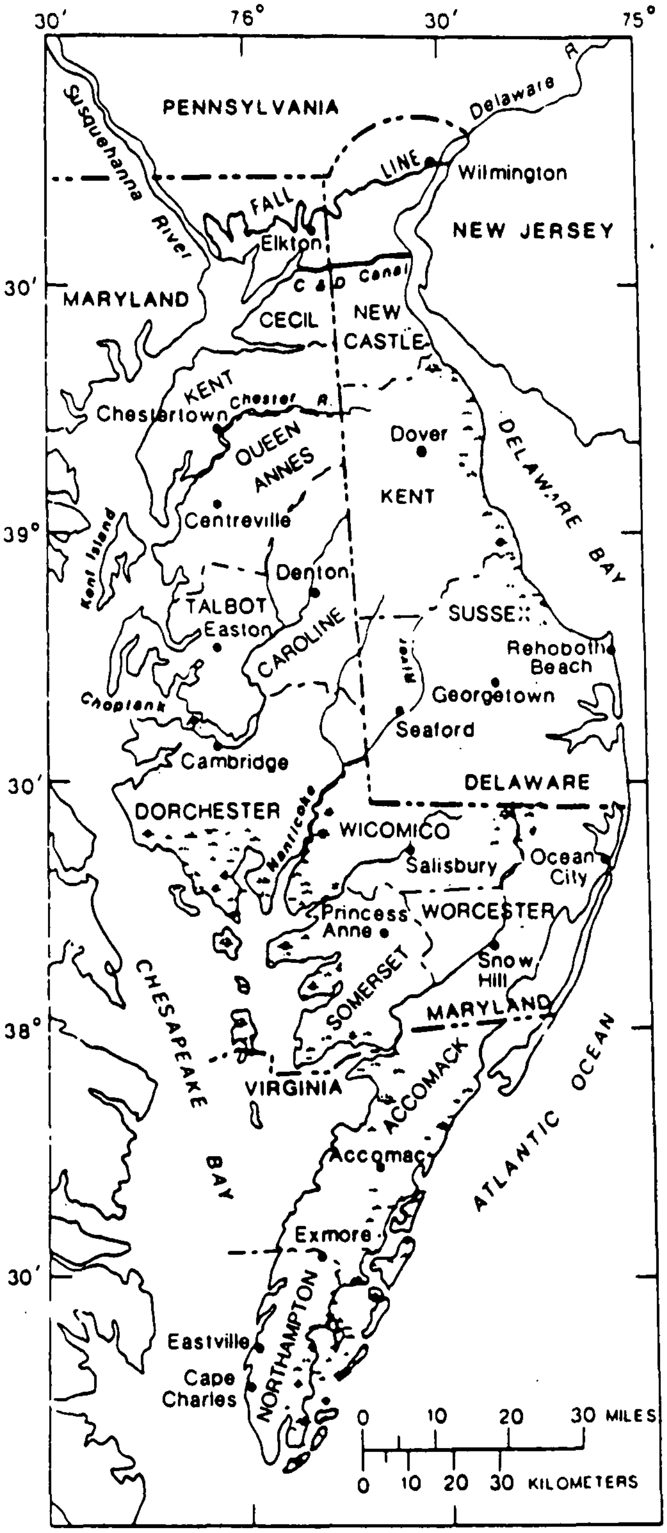


Figure 1. Location of the Study Area

Shore is discussed in the next chapter. The information is based on various planning documents, including predictions of population growth.

The source of potable water in the area is largely ground water, which is drawn from aquifers that are generally confined by less permeable layers. The hydrogeology of these layers and their extent is discussed in the following chapter. It is based largely on information furnished by the U.S. Geological Survey (USGS) and the Maryland Geological Survey (MGS), an agency of the Maryland Department of Natural Resources.

In addition, unconfined aquifers are used throughout the Eastern Shore for some domestic supplies. The household use of these surficial aquifers with high nitrate content presents a significant health hazard. Controlling the nitrate levels is a major focus of the Chesapeake Bay non-point source pollution program.

The Salisbury area is unique, since it depends largely on water drawn from shallow, partially unconfined aquifers (water-bearing strata), which are more susceptible to contamination from the downward percolation of surface water. This area is high-lighted separately.

A local, but temporary, problem related to the Eastern Correctional Institution occurred as a result of excessive withdrawal of water from a relatively shallow aquifer. This resulted in a number of shallow, local wells running dry. This problem has since been corrected by using a deep well into the Patapsco formation instead. This case is discussed in more detail later in this report.

Previous studies, and most recently USGS's National Water-Quality Assessment Program (NAWQA), working in coordination with State and local agencies, have focused on an analysis of water resources on the Delmarva Peninsula. Data collected and analyzed by the responsible USGS Agency have been made available for inclusion in this review. Special emphasis was placed on nitrates, which result from agricultural application of various fertilizers, as well as, insecticide and herbicide products, as well as unsewered domestic effluents. These highly soluble chemicals are found in surficial waters in the vicinity of agricultural areas, but are not found in the deeper, confined aquifers.

It is generally concluded that the most serious threat to water quality is salt water intrusion into the confined aquifers. This is exacerbated by heavy water withdrawal, which promotes recharge of the permeable strata by brackish or saline waters. The threat is generally confined to geographical areas in the vicinity of salt water bodies. The threat becomes more critical as population growth occurs, leading to an increased rate of water withdrawal. The Kent Island area, where the problem is among the most serious, is discussed in some detail.

The largest users of water on the Eastern Shore is the Ocean City area, including the western shore of Assawoman Bay and Sinepuxent Bay as well as the southern portions of Sussex County in Delaware. Since this area is of such economic importance to Maryland and the potential threat of salt water intrusion is very real, a separate chapter is devoted to that area.

WATER USAGE

The Delmarva peninsula is largely devoted to agriculture and has only few towns. However, there are three areas that have experienced significant growth, and these are expected to continue growing, i.e. Kent Island, the Salisbury area, and the Ocean City area. These areas receive special attention in this report.

The 1987 USGS report [2] states that commercial and industrial use (use by public water suppliers, including municipalities, county-operated systems and private water companies) accounted for 51 percent of the total withdrawals in Delaware and Maryland. Irrigation and agriculture accounted for more than 35 percent and the balance was largely withdrawn for self-supplied domestic purpose (individually owned wells).

Ground and surface water withdrawal data by county for 1985 are shown in Table 1 [21]. The table shows that Dorchester, Wicomico and Worcester counties accounted for 60 percent of the Eastern Shore's demands. The largest ground water appropriators were Salisbury and Ocean City with average withdrawal rates of 4.9 and 5.1 million gallons per day (mgd) as shown in Table 2 [21].

Table 1

1985 Summary of Ground and Surface Water Withdrawal*

(MGD)

	Ground	Surface	Total	Fraction Gd/Total
Caroline	8.673	4.383	13.056	.66
Dorchester	11.676	2.886	14.562	.80
Kent	4.430	0.249	4.679	.95
Queen Anne's	5.198	2.528	7.726	.67
Somerset	3.969	0.448	4.417	.90
Talbot	4.921	0.611	5.532	.89
Wicomico	15.923	0.969	16.892	.94
Worcester	11.908	0.607	12.515	.95
Total	66.698	12.681	79.379	

* Without power plant usage

Surface water usage in Caroline, Dorchester and Queen Anne's counties is primarily for farm irrigation. Dorchester county also has some commercial uses for surface water.

Table 2
1985 Largest Groundwater Appropriators

		Average Withdrawal (mgd)
Caroline	Federalsburg	0.727
Dorchester	Cambridge	2.713
Somerset	Crisfield	0.910
Talbot	Easton	1.338
Wicomico	Salisbury	4.922
	Perdue (Salisbury)	1.901
Worcester	Ocean City	5.119
	Showell Farms	0.976

The use of ground water in Maryland by use category and by counties is shown in Table 3 [21]. It is shown that the principal ground water use in Caroline, Dorchester, Kent and Queen Anne's counties was for farm irrigation. In addition to ground water, those counties relied heavily on surface water to supplement farm irrigation. In Somerset, Talbot, Wicomico and Worcester counties water distribution systems were the heaviest users. In addition, domestic uses and livestock watering, as well as commercial and industrial uses were important, particularly in Wicomico and Worcester counties.

Table 3.

1985 County Ground Water Use in Maryland by Use Category

(mqd)

County	Water Distribution Systems	Domestic	Residential Heat Pumps	Farm Irrigation	Irrigation Other	Livestock Watering	Commercial	Industrial	Mining	Institutions	Subtotal Without Power Plants	Power Plants	Total
Allegany	0.471	1.179	0.007	0.00	0.005	0.019	0.130	0.018	0.002	0.031	1.700	0.000	1.862
Anne Arundel	29.581	8.114	0.411	0.01	0.066	0.019	1.495	2.602	0.061	3.575	45.934	0.000	45.934
Baltimore	0.018	4.241	0.035	0.02	0.144	0.182	0.849	3.519	4.363	0.148	13.519	0.000	13.519
Baltimore City	0.000	0.000	0.003	0.00	0.003	0.000	0.062	3.750	0.007	0.000	3.825	0.000	3.825
Calvert	0.780	2.256	0.042	0.04	0.011	0.004	0.443	0.022	0.000	0.182	3.780	0.260	4.040
Caroline	1.658	1.134	0.041	4.41	0.004	0.709	0.480	0.167	0.000	0.070	8.673	0.000	8.673
Carroll	1.245	4.970	0.042	0.03	0.009	0.588	0.276	0.675	0.316	0.083	8.234	0.000	8.234
Cecil	1.149	2.859	0.010	0.02	0.055	0.245	0.457	0.056	0.142	0.072	5.065	0.000	5.065
Charles	4.838	2.931	0.010	0.01	0.043	0.023	0.341	0.017	0.018	1.856	10.087	0.607	10.694
Dorchester	3.271	1.096	0.008	5.73	0.002	0.384	0.715	0.445	0.000	0.025	11.676	0.021	11.697
Frederick	1.491	4.740	0.041	0.00	0.013	1.565	0.918	0.317	2.279	0.268	11.632	0.000	11.632
Garrett	0.231	1.454	0.000	0.00	0.520	0.246	0.262	0.009	1.144	0.023	4.051	0.000	3.889
Harford	3.707	4.841	0.048	0.11	0.013	0.324	0.304	0.097	0.143	0.136	9.723	0.000	9.723
Howard	0.000	1.996	0.028	0.02	0.002	0.120	0.255	0.038	0.000	0.073	2.532	0.000	2.532
Kent	0.834	0.719	0.023	1.13	0.678	0.253	0.109	0.661	0.000	0.023	4.430	0.000	4.430
Montgomery	0.295	2.418	0.227	0.02	0.127	0.200	0.250	0.050	0.361	0.115	4.063	0.000	4.063
Prince George's	2.845	1.218	0.013	0.01	0.150	0.315	0.245	0.021	0.017	0.905	5.739	0.900	6.639
Queen Anne's	0.491	1.847	0.119	1.92	0.008	0.253	0.403	0.103	0.005	0.049	5.198	0.000	5.198
St. Mary's	2.107	3.246	0.026	0.00	0.052	0.065	0.233	0.042	0.011	1.324	7.106	0.000	7.106
Somerset	1.483	0.872	0.000	0.63	0.020	0.791	0.140	0.009	0.001	0.023	3.969	0.000	3.969
Talbot	1.889	1.100	0.068	0.40	0.410	0.218	0.685	0.135	0.000	0.016	4.921	0.000	4.921
Washington	0.490	2.447	0.012	0.01	4.573	0.650	0.200	0.011	0.086	0.303	8.782	0.000	8.782
Wicomico	5.670	2.736	0.316	1.76	0.065	1.272	1.711	2.331	0.001	0.061	15.923	0.000	15.923
Worcester	5.656	0.775	0.135	0.22	0.628	1.261	2.402	0.806	0.000	0.025	11.908	0.000	11.908
Total	70.200	59.189	1.665	16.50	7.601	9.706	13.365	15.901	8.957	9.386	212.47	1.788	214.258

WATER SOURCES

Regional Perspective

The Coastal Plain is underlain by a wedge of unconsolidated sediments that thicken seaward, ranging from 0 feet at the fall line in the north, to over 8000 feet along the Atlantic coast in Maryland. On the basis of hydrological and lithological properties of these unconsolidated sediments, a series of confined aquifers and intervening confining units have been identified throughout the peninsula. The deeper confined aquifers are overlain by an extensive surficial, unconfined aquifer, which is primarily under water-table conditions [2]. In general the flow in the confined aquifers proceeds from the northwest to the southeast, although the direction of flow varies between aquifers as well as within aquifers [2].

A north-south hydrogeological section across Delmarva Peninsula identifying the stratification of the important aquifers is shown in Figure 2 [2]. The sections of the aquifers that are fresh or saline are also identified. The irregularity of the aquifers as well as connections between surficial aquifers and the Manokin and Pocomoke aquifers are also shown. In some areas the confining layers between the Manokin and the Pocomoke

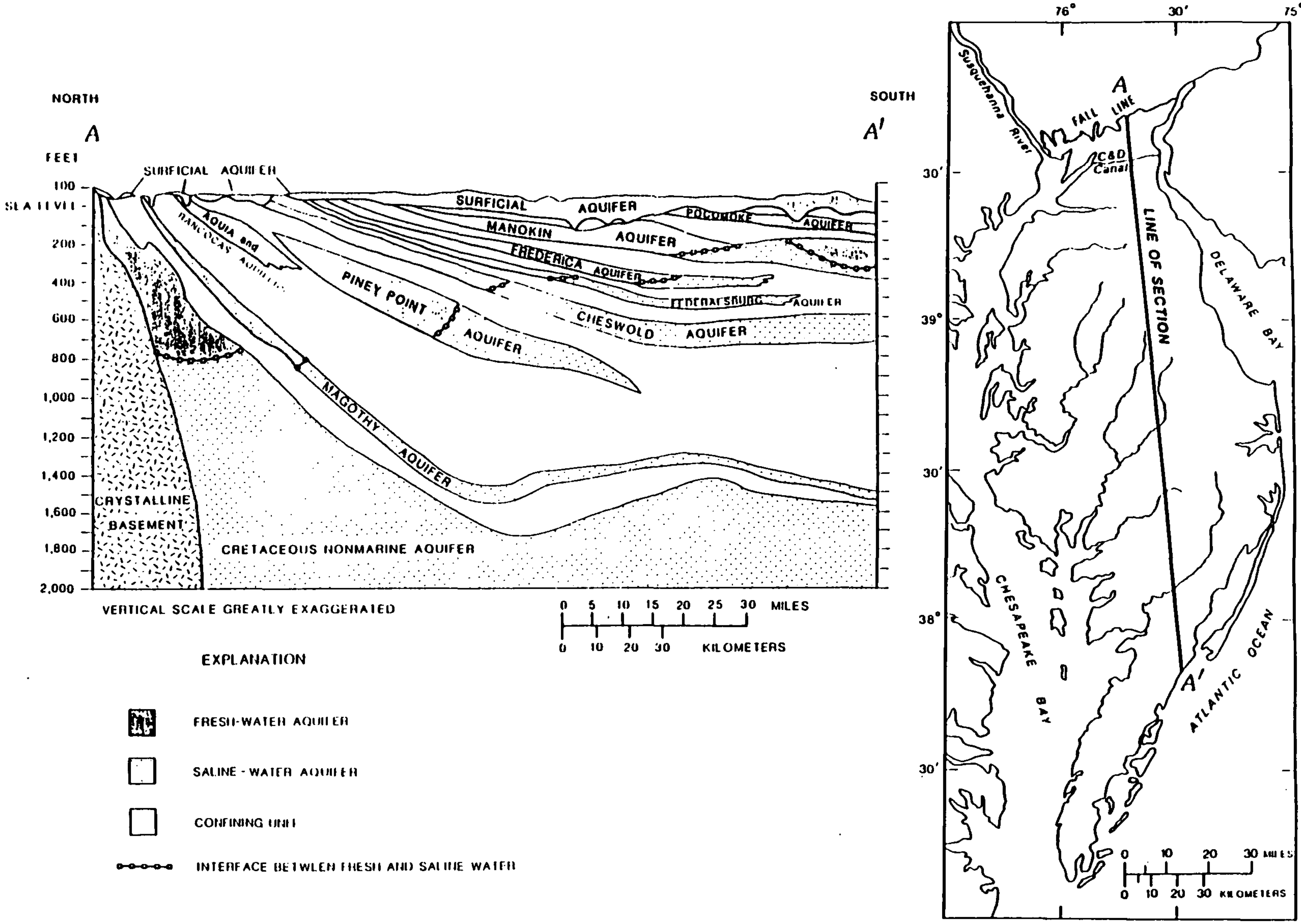


Figure 2. – Hydrogeologic section across the Delmarva Peninsula (modified from Cushing and others, 1973).

aquifer are thin or absent and the two act as one hydrologic unit. This is particularly important in the eastern Worcester county area.

Another section across the Eastern Shore of Maryland from the Chesapeake Bay to Ocean City identifying the important aquifers is shown in Figure 3 [2]. The existence of both shallow aquifers and the important Salisbury paleochannel in the Salisbury area must be emphasized.

The general extent of aquifers containing fresh water is shown in Figure 4 [2]. Of the upper confined aquifers in the upper tertiary series (Miocene), the Cheswold aquifer supplies most of the water to the Dover, Delaware area and the Federalsburg and Frederica aquifers to the central peninsula (Caroline County). The Manokin (including the Ocean City aquifer) and Pocomoke aquifers supply water to Worcester County and the Ocean City/Rehoboth areas.

Of the middle confined aquifers, the Aquia aquifer supports Kent (Chestertown), Talbot County (Easton) and Oxford. The Piney Point aquifer is a very productive aquifer and supports primarily Caroline, Dorchester, and Talbot counties, with Cambridge and Denton being the largest users. It is used extensively by the City of Dover, Delaware. The combined use by Dover, Cambridge and Denton has resulted in a regional decline that is being noticed

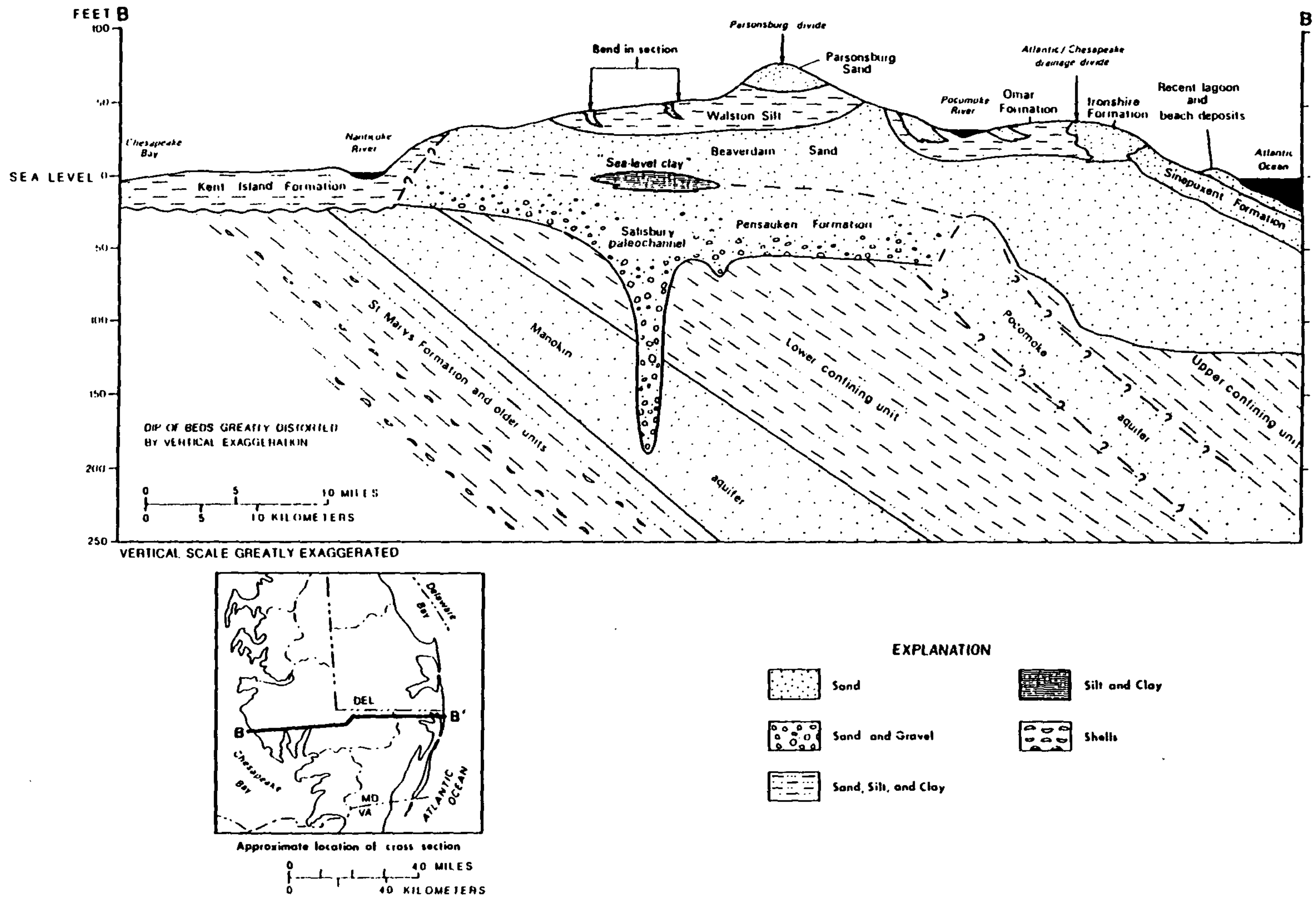


Figure 3.– Generalized section across the Delmarva Peninsula from Salisbury, Md., and Chesapeake Bay to Ocean City, Md., showing an interpretation of the relations between the surficial deposits and other geologic units (section based on work by Demarest, Biggs, and Kraft (1981), Owens and Denny (1979), Weigle (1974), Hansen (1966, 1981), and test-hole data collected by U.S. Geological Survey).

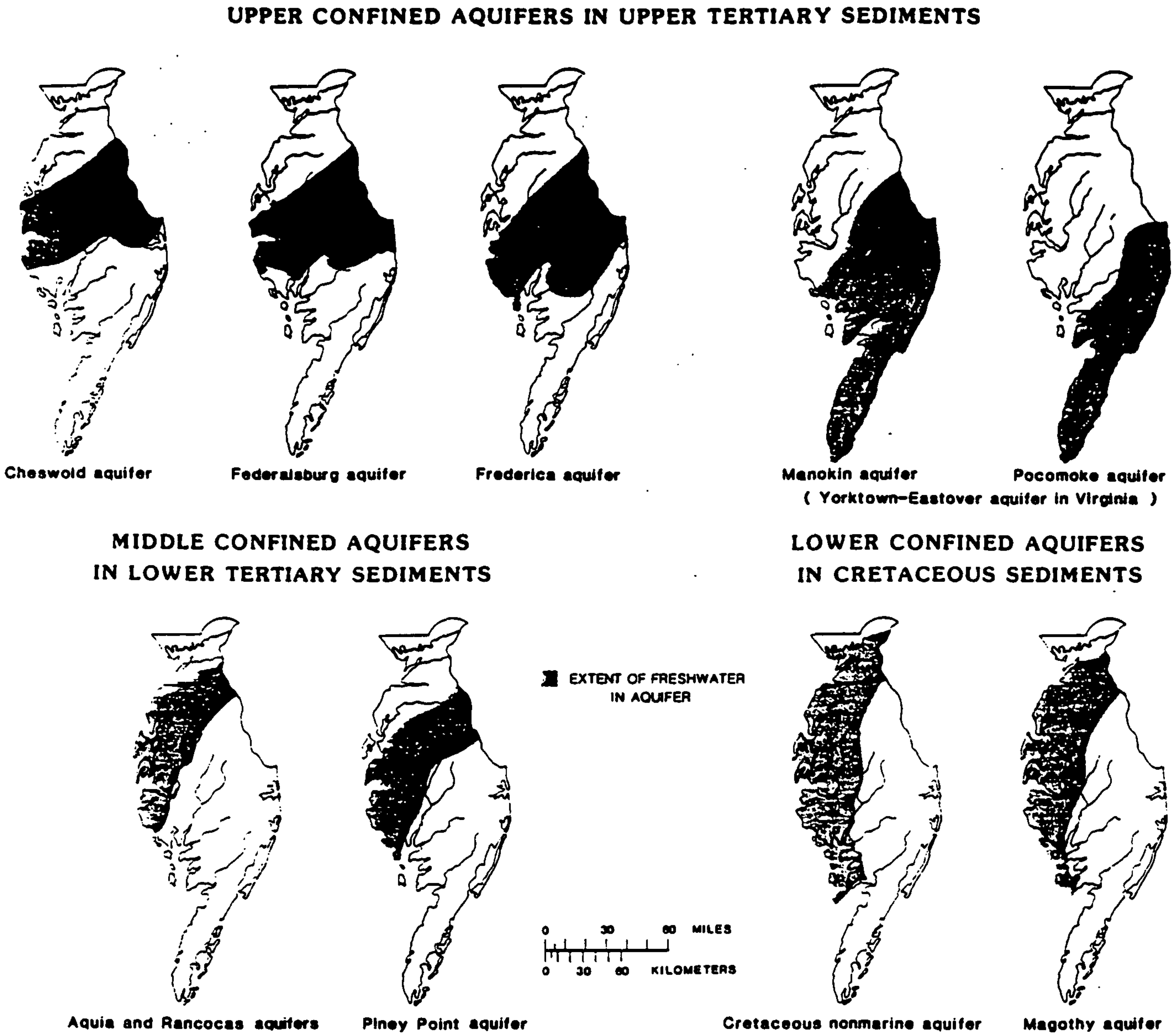


Figure 4 – Extent of aquifers containing freshwater in study area (modified from Cushing and others, 1973).

by the users in rural areas. The potential for adverse impact, the observable decline in waterlevels, and the interstate nature of the regional decline in the potentiometric surface make this an issue of concern.

The Magothy aquifer, of the lower confined aquifers, supports Kent County, Talbot (Easton), Somerset (Crisfield) and Cambridge.

About 70 percent of the water used by public water suppliers is withdrawn from deep, confined aquifers. About 78 percent of the agricultural and 66 percent of the domestic withdrawals come from the surficial aquifers.

While the aforementioned confined aquifers serve most of the peninsula, the principal ground water source in central Wicomico County, including Salisbury, is the semiconfined Columbia aquifer. Salisbury, particularly, is served by the Salisbury paleochannel which reaches to a depth of almost 200 feet.

Withdrawal data (in mgd) for different aquifers are shown by counties in Table 4 [21].

TABLE 4

Reported Withdrawal of Ground Water in Maryland by Aquifer and County[1] (mgd)

	COASTAL PLAIN PROVINCE																			PIEDMONT PROVINCE					
System	Quaternary			Tertiary									Cretaceous							Ordivician	Cambro-Ordivician to Late Precambrian				
Series	Holocene-Pleistocene	Pleistocene-Pliocene		Miocene					Eocene-Paleocene				Upper Cretaceous			Lower Cretaceous									
Group				Chesapeake Group						Pamunkey Group					Potomac Group										
Formation/ Aquifer Name / County	Quaternary	Talbot Formation	Pleistocene-Pliocene Series	Cheswold Aquifer	Federalsburg Aquifer	Frederica Aquifer	Manokin Aquifer	Pocomoke Aquifer	Piney Point Formation	Nanjemoy Formation	Aquia Formation	Paleocene Series	Magothy Formation	Monmouth Formation	Raritan Formation	Nonmarine Cretaceous	Patapsco Formation	Paluxent Formation	Potomac Group	Peach Bottom Slate	Urbana Formation	Libertytown Metarhyolite	Ijamsville Formation-Marburg Schist	Sams Creek Metabasalt	Wakefield Marble
Allegany																									
Anne Arundel											.330		4.365				23.593	7.844							
Baltimore																		3.655							
Baltimore City																		3.784	.017						
Calvert									.038	.230	1.014		.100												
Caroline	.136			.243	.242	.517	.162		.876																
Carroll																							.037	.060	1.150
Cecil													.081			.650	.068	.122	.022						
Charles											.105		3.147				3.160	.858	.013						
Dorchester	1.071				.017	.002	.053		3.171																
Frederick																					.030	.021	.340	.004	
Garrett																									
Harford	1.141	.098																.012	2.403	.008					
Howard																		.012							
Kent											.641		.982	.551	.007										
Montgomery																									
Prince George's											.007		1.502				.869	2.374							
Queen Anne's	.001										.438		.001	.332											
St. Mary's									.536	.010	2.861		.024						.010						
Somerset							.447	.087				.034	.880			.060									
Talbot	.751			.064	.053				.196		.409		1.387												
Washington																									
Wicomico	8.773					.053	.155																		
Worcester	1.858		.347				5.450	1.432																	
Total	13.731	.098	.347	.307	.312	.572	6.267	1.519	4.817	.240	5.805	.034	12.469	.883	.007	710	27.690	18.661	2.465	.008	.030	.021	.377	.064	1.150

1 The geologic nomenclature used in this table may not correspond with that adopted by the Maryland Geological Survey or the U.S. Geological Survey. Consequently, the figures are probably lower than actual withdrawals from the aquifers. Cases exist where the supplying aquifer is undifferentiated from supplying aquifer.

Recharge Areas

In many cases the areas for recharging confined aquifers are far removed from the withdrawal (water usage) areas.

The youngest aquifers, Quaternary sediments are mostly surficial, acting as water-table aquifers. In eastern Worcester county these aquifers are semiconfined and are recharged by infiltration of precipitation. Therefore, development that significantly reduces the effect in infiltration or that causes impurities to infiltrate may impact a usage area elsewhere, given sufficient time.

The Pokomoke aquifer system in eastern Worcester county is also recharged from downward movement through the Quaternary sediments. It should be noted that under pumping stress the differential pressure across the confining layer between aquifers results in the increasing downward movement of water. This can be a significant source of recharge as well as a potential source for contamination.

Of the Miocene aquifers, the Manokin recharges directly in up-dip areas by downward movement of water through the Quaternary segments in east Dorchester and north Wicomico counties.

The Piney Point aquifer has no outcrop areas and is recharged from overlying or underlying aquifers. Principal recharge is from the Cheswold aquifer.

The Aquia formation is of particular importance on the northern part of the peninsula. However, part of its recharge is derived over a wide area from outcrop areas which extend from Potomac River Bluffs in western Charles county to the upper reaches of the Sassafras River in southeast Cecil county.

The Magothy aquifer receives most of its recharge near its up-dip limits which outcrop in Prince George's, Anne Arundel, Kent and Cecil counties.

Salisbury

The City of Salisbury is singled out in this report because it obtains its water supply from a Coastal Plain unconfined aquifer, the Quaternary (Columbia) aquifer. The Quaternary sediments are of riverine and estuarine origin and are composed predominantly of sand and gravel with some layers of silty clay and clay. About 2 1/2 miles north of the center of the city is the Salisbury paleochannel, one of the most productive zones of the Quaternary aquifer [13]. The paleochannel is an ancient river channel that eroded the lower aquiclude into the underlying

Manokin aquifer and locally into the St. Mary's formation. In general, paleochannels are formed by downcutting into confining units. These channels are filled with sediments more permeable than the confining layers, but less permeable than the aquifers through which they cut [2]. Although in the Salisbury area, the paleochannel sediments are coarser (more permeable) than the Manokin aquifer.

The City of Salisbury obtains its water supply from nine wells in the Municipal Park along the banks of the Beaverdam Creek with a total well depth averaging 56 feet. In addition, two Paleo wells are located about 2 1/2 miles north of town with depths of 160 and 195 feet respectively. Records indicate about equal total pumpage for the Park wells and the Paleo wells. The finished water meets all drinking water quality standards [32].

Data show that the Quaternary aquifers are hydraulically connected and the natural gradients are very gentle. Therefore, pumpage from larger production wells can easily result in flow across natural water divides. Reports also have shown that the paleochannel aquifer is hydraulically connected with the adjoining Quaternary aquifers and the underlying Manokin aquifer [32].

The Maryland Department of the Environment report [32] concludes that:

"In Salisbury's case the flow system is more complex due to the presence of nearby surface water sources and the highly permeable paleochannel. Both of these conditions make the City's supply vulnerable to contamination from sources further afield than might typically be the case. The City's wellhead protection program should address these concerns in addition to protecting the 1-year and 10-year WHPA Code areas of the unconfined coastal plain aquifers.

Eastern Correctional Institution

Until recently, Princess Anne, the University of Maryland Eastern Shore, and the Eastern Correctional Institution (ECI), located 2 1/2 miles south of Princess Anne, as well as numerous domestic and farm wells, drew their water from the Manokin aquifer which, in that area, is relatively shallow. The depth of SOM-Ce 44, at ECI, drilled in 1985, is 240 feet and yields about 180 gpm. Since that well was planned for a much smaller ECI population than actually resides in that institution, the excess drawdown developed cones of depression of such a magnitude that a large number of domestic wells in the area ran dry. The water levels in the Manokin aquifer in the vicinity have declined by as much as 30 feet in one year since pumpage began at the institution in August 1987 [12].

To relieve the situation a test well, SOM-Ce 95, was drilled into the Patapsco formation. That well draws from a depth of 1135-1200 feet and yields 393 gpm. Test samples indicated high sodium (330 mg/L) and bicarbonate (800 mg/L) levels and a high alkalinity (pH of 8.2). This is considerably higher than the current Manokin levels of 263 mg/L for sodium and 420 mg/L for bicarbonate. In addition, the water temperature of the deep well was 27.4°C. Although the chloride, sulfate and silica concentrations were relatively low, they were sufficiently high for the Maryland Environmental Service (MES) to treat the water using Reverse Osmosis Filters (RO), otherwise precipitates would clog heat exchangers or boilers. The total dissolved solids content of 829 mg/L also exceeded standards for drinking water of 500 mg/L and the current Manokin level of 700 mg/L [12].

A water treatment plant has been constructed which employs a reverse osmosis (RO) unit to bring the quality of the water from the deep well to drinking water standards. The deep well will provide relief to Princess Anne and other Manokin aquifer users.

Piney Point Aquifer

The MGS investigated the Piney Point aquifer at Cambridge, with the results shown in MGS report R.I. No 31 in 1979 [20]. MGS states [11C2] that "pumpage from the Piney Point aquifer was greater in the 1950's than today. In the 1950's Piney Point withdrawals were greater because pumpage from canneries (now closed) and by the City of Cambridge, which used the Piney Point as a sole source. At present the city pumps from both the Magothy-Patapsco aquifer system and the Piney Point aquifer so that losses are not as great". Figures 5A and 5B for wells DO-Ce

78 and DO-Ce 5, do not show a systematic decline for the 1987-1992 time period [11C2].

On the other hand, Figures 5C and 5D, for Caroline County wells (CO-Ce 5 and CO-Bd53, do show a modest decline due in part to additional Piney Point pumpage resulting from nitrate contamination of the water table sources. The Piney Point hydrograph for DO-Bg 59 at Hurlock in northern Dorchester County, Figure 5E, also shows a modest decline for the same reason [11C2].

These are good examples of the interplay between contamination of water table sources, probably as a result of agricultural activities, and groundwater requirements. It also emphasizes the shared relationship and responsibility between DOE, protecting the quality of the water table resources, and the DNR, assuring that all users have an adequate supply of potable water.

Finally, GSAC believes that the general application of the 80% level policy should be reexamined. On the one hand, general drawdown to an 80% level could impact previous updip users with shallow wells. On the other hand, under some conditions, such withdrawal may be sufficient to cause salt water intrusion into the water supply.

MARYLAND--Continued

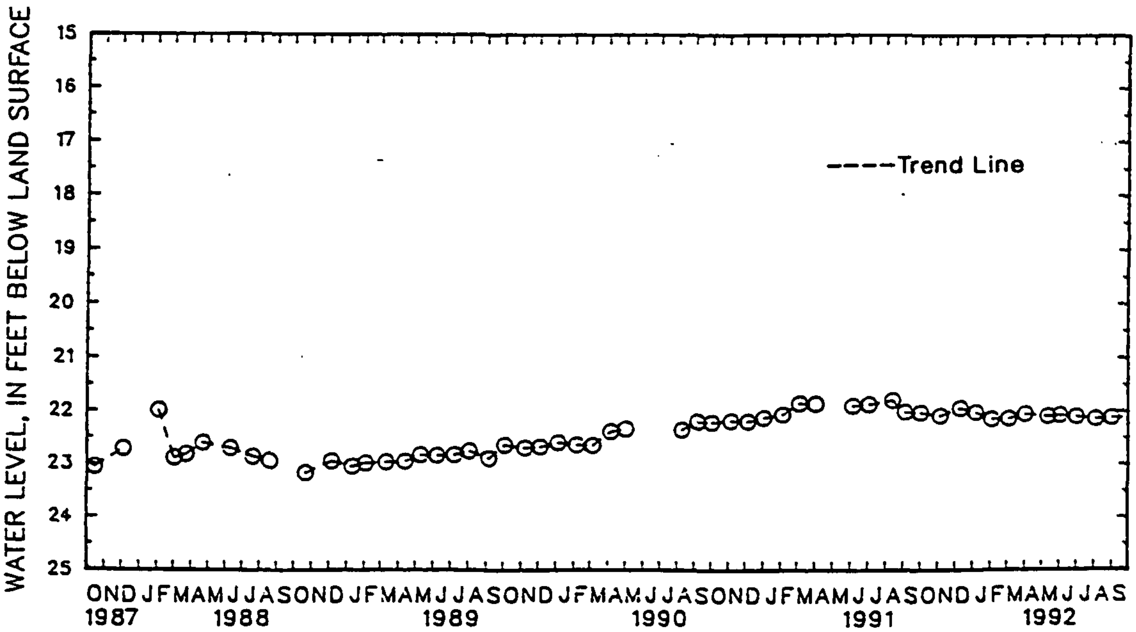
DORCHESTER COUNTY--Continued

WELL NUMBER.--DO Ca 78. SITE ID.--383243076042301. PERMIT NUMBER.--DO-66-0026.
LOCATION.--Lat 38°32'43", long 76°04'23", Hydrologic Unit 02060005, at Stone Boundary Rd., Cambridge.
Owner: City of Cambridge.
AQUIFER.--Piney Point Formation of Middle Eocene age. Aquifer code: 124PNPN.
WELL CHARACTERISTICS.--Drilled, unused, artesian well, depth 517 ft; casing diameter 12 in.; screen diameter 12 in. from 360.3 to 363.7 ft, 368 to 380 ft, 385 to 400 ft, 405 to 420 ft, 425 to 440 ft, 445 to 460 ft, 465 to 480 ft, and 485 to 500 ft.
INSTRUMENTATION.--Monthly measurements with chalked steel tape by USGS personnel.
DATUM.--Elevation of land surface is 15 ft above National Geodetic Vertical Datum of 1929, from topographic map.
Measuring point: Top of casing, 1.10 ft above land surface.
REMARKS.--Maryland Water-Level Network observation well.
PERIOD OF RECORD.--October 1977 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 21.80 ft below land surface, August 13, 1991; lowest measured, 26.39 ft below land surface, Oct. 4, 1977.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 1	22.03	DEC 10	21.95	FEB 3	22.15	APR 2	22.06	JUN 2	22.08	AUG 4	22.15
NOV 5	22.09	JAN 6	22.03	MAR 4	22.14	MAY 12	22.10	JUL 1	22.11	SEP 1	22.13

WATER YEAR 1992 HIGHEST 21.95 DEC 10, 1991 LOWEST 22.15 FEB 3, 1992 AUG 4, 1992



5 YEAR HYDROGRAPH
OCTOBER 1, 1987 THROUGH SEPTEMBER 30, 1992

Figure 5A.

GROUND-WATER LEVELS

MARYLAND--Continued

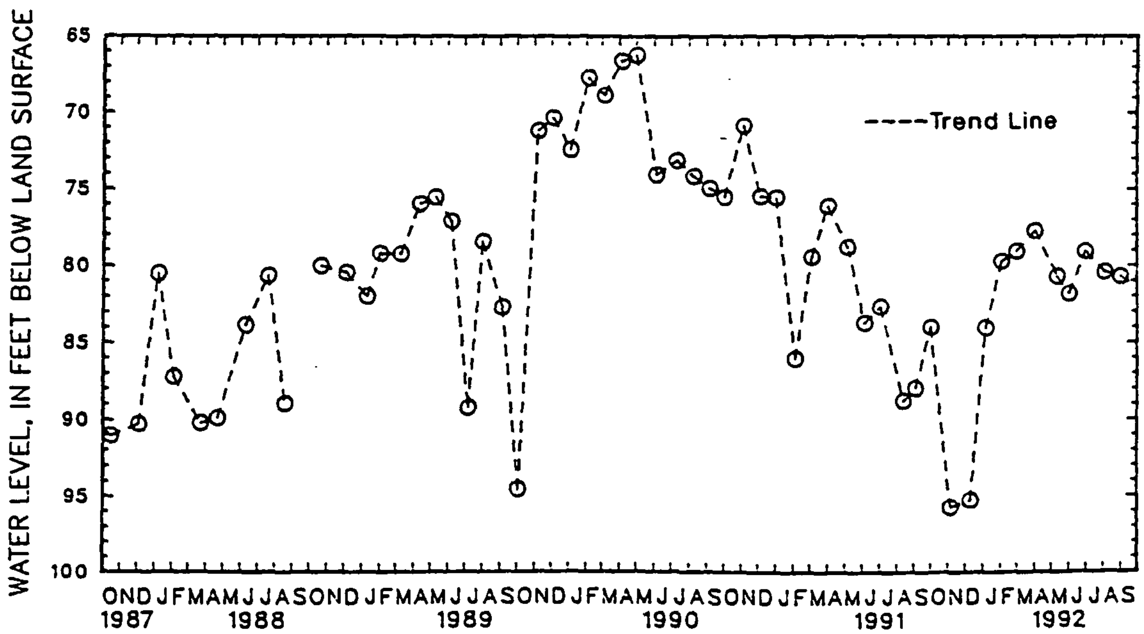
DORCHESTER COUNTY--Continued

WELL NUMBER.--DO Ca 5. SITE ID.--383340076041601.
LOCATION.--Lat 38°33'40", long 76°04'16", Hydrologic Unit 02060005, at Cambridge Pumping Station.
Owner: Municipal Utilities Commission.
AQUIFER.--Piney Point Formation of Middle Eocene age. Aquifer code: 124PNPN.
WELL CHARACTERISTICS.--Drilled, unused, artesian well, depth 405 ft; casing diameter 12 in., to 385 ft.
INSTRUMENTATION.--Monthly measurements with chalked steel tape by USGS personnel.
DATUM.--Elevation of land surface is 18 ft above National Geodetic Vertical Datum of 1929, from topographic map.
Measuring point: Top of casing, 4.00 ft above land surface.
PERIOD OF RECORD.--October 1977 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured 66.23 ft below land surface, May 1, 1990; lowest measured, 115.06 ft below land surface, Aug. 29, 1978.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 1	84.03	DEC 10	95.30	FEB 3	79.74	APR 2	77.73	JUN 2	81.85	AUG 4	80.43
NOV 5	95.75	JAN 6	84.07	MAR 1	79.09	MAY 12	80.74	JUL 1	79.09	SEP 1	80.75

WATER YEAR 1992 HIGHEST 77.73 APR 2, 1992 LOWEST 95.75 NOV 5, 1991



5 YEAR HYDROGRAPH
OCTOBER 1, 1987 THROUGH SEPTEMBER 30, 1992

Figure 5B.

GROUND-WATER LEVELS

MARYLAND--Continued

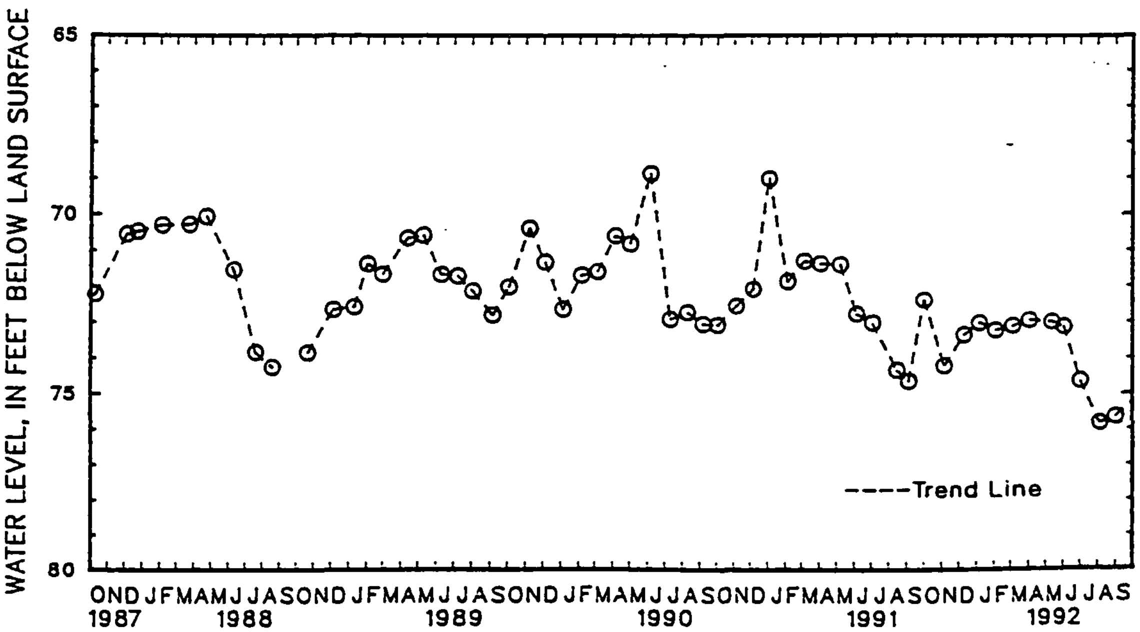
CAROLINE COUNTY--Continued

WELL NUMBER.--CO Dd 47. SITE ID.--385217075490601. PERMIT NUMBER.--CO-73-0486.
LOCATION.--Lat 38°52'17", long 75°49'06", Hydrologic Unit 02060005, at Denton Sewage Lagoon.
Owner: U.S. Geological Survey.
AQUIFER.--Piney Point Formation of Middle Eocene age. Aquifer code: 124PNPN.
WELL CHARACTERISTICS.--Drilled, observation, artesian well, depth 380 ft; casing diameter 4 in., to 86 ft; casing diameter 2 in. from 86 to 365 ft; screen diameter 2 in. from 365 to 375 ft.
INSTRUMENTATION.--Monthly measurements with chalked steel tape by USGS personnel.
DATUM.--Elevation of land surface is 46 ft above National Geodetic Vertical Datum of 1929, from topographic map. Measuring point: Top of casing, 2.40 ft above land surface.
REMARKS.--Maryland Water-Level Network observation well.
PERIOD OF RECORD.--April 1976 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 62.78 ft below land surface, May 27, 1976; lowest measured, 75.88 Ft below land surface, Aug. 4, 1992.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 1	72.40	DEC 10	73.39	FEB 3	73.26	APR 2	72.97	JUN 2	73.16	AUG 4	75.88
NOV 5	74.27	JAN 6	73.05	MAR 4	73.13	MAY 12	73.02	JUL 1	74.69	SEP 1	75.70

WATER YEAR 1992 HIGHEST 72.40 OCT 1, 1991 LOWEST 75.88 AUG 4, 1992



5 YEAR HYDROGRAPH
OCTOBER 1, 1987 THROUGH SEPTEMBER 30, 1992

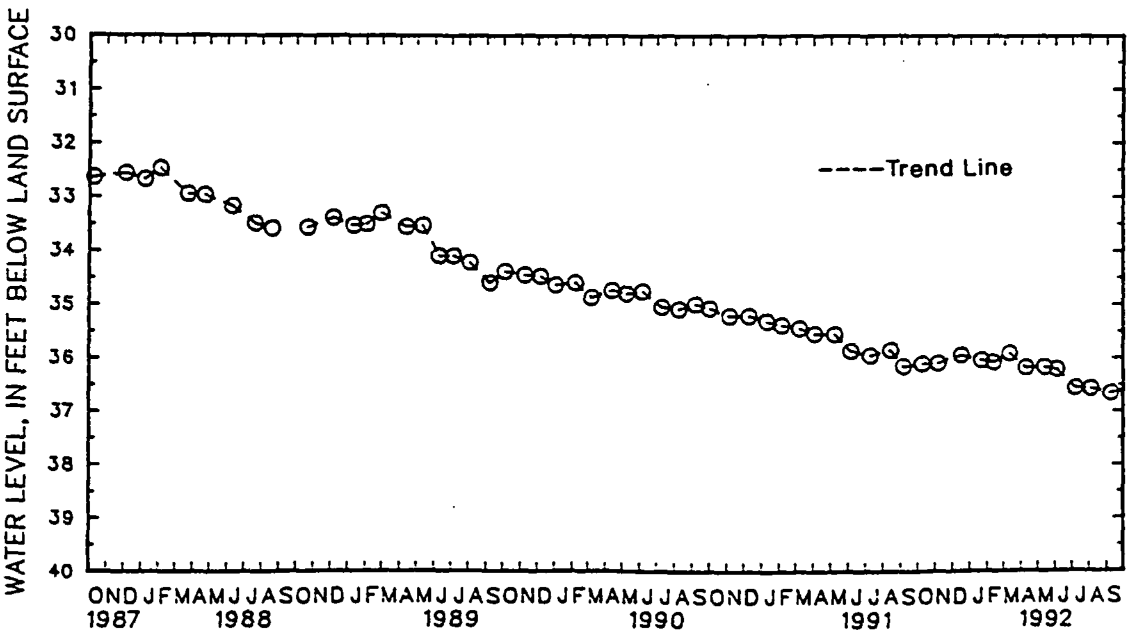
Figure 5C.

WELL NUMBER.--CO Bd 53. SITE ID.--390227075470201. PERMIT NUMBER.--CO-73-0541.
LOCATION.--Lat 39°02'27", long 75°47'02", Hydrologic Unit 02060005, near MD Rt. 311, Goldsboro.
Owner: U.S. Geological Survey.
AQUIFER.--Piney Point Formation of Middle Eocene age. Aquifer code: 124PNPN.
WELL CHARACTERISTICS.--Drilled, observation, artesian well, depth 312 ft; casing diameter 6 in., to 70 ft; casing diameter 2 in. from 70 to 300 ft; screen diameter 2 in. from 300 to 312 ft.
INSTRUMENTATION.--Monthly measurements with chalked steel tape by USGS personnel.
DATUM.--Elevation of land surface is 60 ft above National Geodetic Vertical Datum of 1929, from topographic map.
Measuring point: Top of casing, 2.20 ft above land surface.
REMARKS.--Maryland Water-Level Network observation well.
PERIOD OF RECORD.--February 1976 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 28.64 ft below land surface, Dec. 10, 1976; lowest measured, 36.58 ft below land surface, Aug. 4, 1992.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1991 TO SEPTEMBER 1992

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 9	36.11	DEC 17	35.95	FEB 12	36.09	APR 10	36.19	JUN 4	36.22	AUG 4	36.58
NOV 6	36.10	JAN 22	36.05	MAR 12	35.92	MAY 13	36.18	JUL 7	36.57		

WATER YEAR 1992 HIGHEST 35.92 MAR 12, 1992 LOWEST 36.58 AUG 4, 1992



5 YEAR HYDROGRAPH
OCTOBER 1, 1987 THROUGH SEPTEMBER 30, 1992

Figure 5D.

GROUND-WATER LEVELS

MARYLAND--Continued

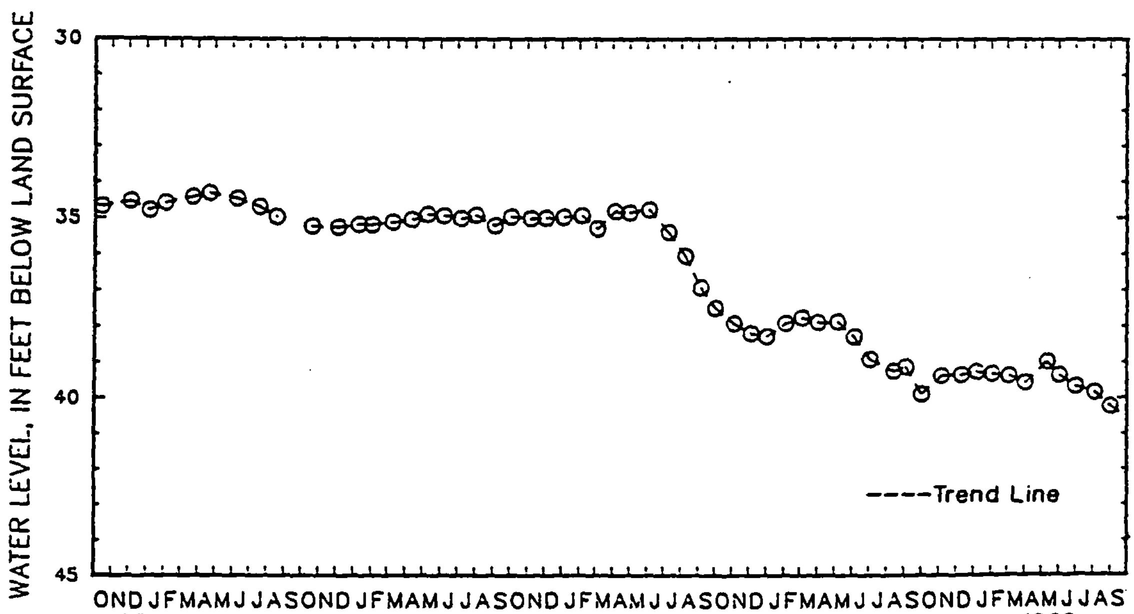
DORCHESTER COUNTY

WELL NUMBER.--DO Bg 59. SITE ID.--383708075503801. PERMIT NUMBER.--DO-73-0612.
LOCATION.--Lat 38°37'08" Long 75°50'38", Hydrologic Unit 02060008, at Hurlock Sewage Treatment Plant.
Owner: U.S. Geological Survey.
AQUIFER.--Piney Point Formation of Middle Eocene age. Aquifer code: 124PNPN
WELL CHARACTERISTICS.--Drilled, observation, artesian well, depth 537 ft; casing diameter 6 in., to 65 ft; casing diameter 2 in. from 65 to 527 ft; screen diameter 2 in. from 527 to 537 ft.
INSTRUMENTATION.--Monthly measurements with chalked steel tape by USGS personnel.
DATUM.--Elevation of land surface is 25 ft above National Geodetic Vertical Datum of 1929, from topographic map.
Measuring Point: Top of casing, 0.60 ft above land surface.
REMARKS.--Maryland Water-Level Network observation well.
PERIOD OF RECORD.--October 1976 to current year.
EXTREMES FOR PERIOD OF RECORD.--Highest water level measured, 31.79 ft below land surface, Aug. 2, 1978; lowest measured, 40.25 ft below land surface, Sept. 1, 1992.

WATER LEVEL, IN FEET BELOW LAND SURFACE, WATER YEAR OCTOBER 1990 TO SEPTEMBER 1991

DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL	DATE	WATER LEVEL
OCT 1	39.90	DEC 10	39.36	FEB 3	39.34	APR 2	39.58	JUN 2	39.38	AUG 4	39.85
NOV 5	39.39	JAN 6	39.28	MAR 4	39.38	MAY 12	39.00	JUL 1	39.68	SEP 1	40.25

WATER YEAR 1992 HIGHEST 39.00 MAY 12, 1992 LOWEST 40.25 SEP 1, 1992



5 YEAR HYDROGRAPH
OCTOBER 1, 1987 THROUGH SEPTEMBER 30, 1992

Figure 5E.

WATER QUALITY

Water quality data are collected throughout the tri-state area primarily for regulatory and public health functions. Data are available from 3 federal, 5 state and 14 local agencies throughout Delmarva.

Inasmuch as these agencies collect and process water quality data for a variety of purposes, it is not surprising that the content and formats form a disparate collection of information. Some collections are automated, many are not, and questions of quality assurance and control regarding the actual figures may not be readily available. An effort by the USGS to combine these various data sets into an integrated database constitutes a major advance in the analysis of Delmarva water quality, use and regulation [2].

NAWQA Study

The USGS National Water-Quality Assessment Program (NAWQA) was established to provide a sound understanding of the natural and human factors that affect water quality. Maryland is fortunate by having the Delmarva Peninsula selected as one of the initial study areas. The area covered in the NAWQA study is shown in Figure 6 [8]. Most of the ground water was sampled from more

CONFINED AQUIFER NETWORK

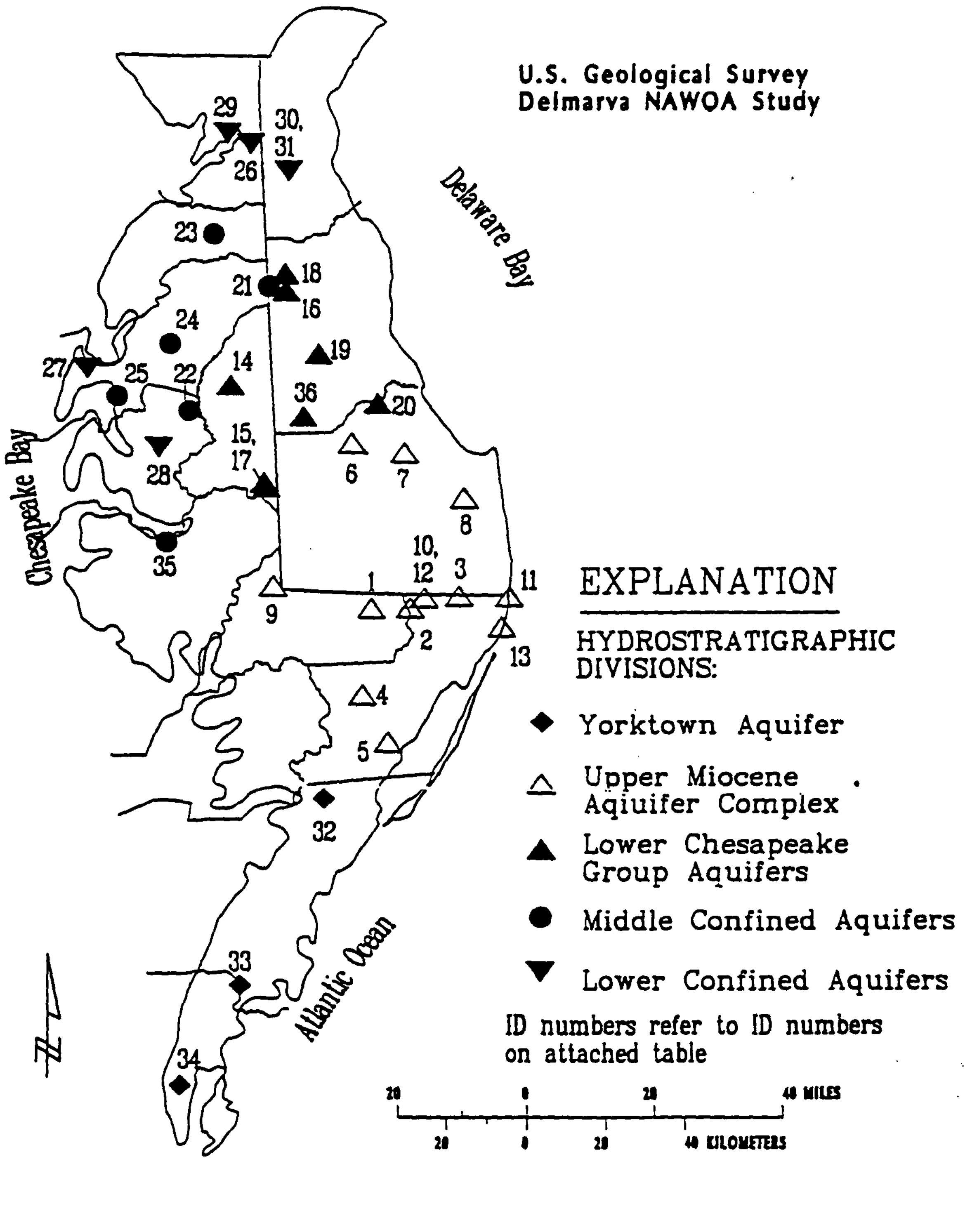


Figure 6. Confined Aquifer Network

than 200 water-table wells and more than 35 wells in the underlying confined aquifers in the 3-state Delmarva Peninsula. A list of the confined aquifers sampled in the Maryland counties is shown in Table 5 [8].

Drinking-water standards and criteria are established by the U.S. Environmental Protection Agency (1986) to safeguard public health and welfare. The levels required to protect public health are defined as "Maximum Contamination Levels (MCL)". The levels set to safeguard human welfare and to provide acceptable ascetic and taste characteristics are usually referred to as "Secondary Maximum Contamination Levels (SMCL)" [2].

The principal recent report covering the study area published to date [8] deals only with analysis of nitrates and pesticides in ground water, primarily drawn from shallow wells. However, additional analyses were performed on preliminary data furnished informally by USGS on the confined aquifers in the Maryland area.

The water samples were analyzed for the characteristics, chemicals and trace elements shown in Table 6 [9]. Not all agents listed in the table were tested for all wells. In particular, testing of organic agents was very sparse. Also, tests rely on results furnished by a variety of sources, as mentioned above.

Table 5
CONFINED AQUIFERS SAMPLED IN NAWQA STUDY

Caroline			
14	CO Cc 100	Frederica	75 ft
15	CO Fd 36	Frederica	140 ft
17	CO Fd 38	Federalsburg	301 ft
Dorchester			
35	DO Ce 21	Piney Point	370 ft
Kent			
23	KE Be 61	Aquia	50 ft
Queen Anne's			
21	QA Bh 46	Piney Point	250 ft
24	QA De 30	Aquia	481 ft
25	QA Fe 7	Aquia	356 ft
27	QA Eb 163	Magothy	714 ft
Talbot			
22	TA Bf 73	Piney Point	288 ft
28	TA Ce 70	Magothy	1184 ft
Wicomico			
1	WI Cg 58	Pokomoke	135 ft
2	WI Ch 47	Cheswold	149 ft
9	WI Bd 68	Manokin	100 ft
Worcester			
3	WO Af 30	Pokomoke	220 ft
4	WO Dc 30	Pokomoke	70 ft
5	WO Ed 46	Pokomoke	210 ft
10	WO Ae 23	Manokin	280 ft
11	WO Ah 37	Manokin	478 ft
12	WO Ae 24	Ocean City	200 ft
13	WO Bh 28	Ocean City	294 ft

Table 6
TESTS PERFORMED BY USG IN NAWQA

Specific Conductance
pH of Water
Alkalinity [CaCO3]
Hardness [CaCO3]

Oxygen
Carbon Dioxide [CO2]
Bicarbonate [HCO3]
Organic Nitrogen [N]
Ammonia [N]
Nitrite [N]
Ortho Phosphate [PO4]
Phosphorus [P]
Organic Carbon [C]
Calcium
Magnesium
Sodium
Sodium Adsorption ratio
Potassium
Chloride
Sulphate
Fluoride
Silica
Arsenic
Barium
Berylium
Boron
Cadmium
Chromium
Cobalt
Copper
Iron
Lead
Manganese
Molybdenum
Nickel
Silver
Strontium
Vanadium
Zinc
Antimony
Aluminum
Lithium
Selenium
Bromide [Br]
Mercury

Gross Beta

Di-Bromo Methane
Di-Chloro-Bromo-Methane
Carbon Tetrachloride
1-2 Di-Chloro Ethane
Bromoform
Chloro-Di-Bromo-Methane
Chloroform
Trans 1,3 Di-Chloro Propene
Cis 1,3 Di-Chloro Propene
Tri-Chloro-Ethylene
Chloro-Ethane
Di-Chloro-Di-Fluoro Methane
Methyl-Bromide
Methyl Chloride
Methylene Chloride
Tetra-Chloro Ethylene
Tri-Chloro-Fluoro-Methane
1,1-Di-Choro Ethane
1,1 Di-Chloro Ethylene
1,1,1 Tri-Chloro Ethane
1,1,2 Tri-Chloro Ethane
1,1,2,2, Tetra-Chloro Ethane
2-Chloro-Ethyl-Vinyl Ether
1,2 Di-Chloro Propane
1,2, Trans-Di-Chloro Ethylene
1,3 Di-Chloro Propene
1,2 Di-Chloro Ethene
1,1, Di-Chloro Propene
2,2 Di-Chloro Propane
1,3, Di-Chloro Propane
1,2,3 Tri-Chloro Propane
1,1,1,2 Tetra-Chloro Ethane
1,2 Di-Bromo Ethane

Benzene
Bromo-Benzene
Chloro-Benzene
1,2 Di-Chloro Benzene
1,3 Di-Chloro Benzene
1,4 Di-Chloro Benzene
Toluene
o-Chloro Toluene
p-Chloro Toluene
Xylene
Ethyl Benzene

Radon 222
Tritium

Propazine
Tri-Fluoralin
Methomyl
Propham
Simetryne
Simazine
Prometone
Prometryne
Vinyl-Chloride
Atrazine
Picloram
2-4 D
2,4,5 - T
Sevin
Silvex
Alachlor
Cyanazine
Dicamba
2,4 - DP
Ametryne
Radon 222
MtribuzinN
Styrene

In general, the data analyzed in the earlier USGS study [2] show that the surficial aquifers generally have low pH (high acidity). The shallow layers also showed higher nitrate content, which decreases with depth and which indicates the presence of human activity. This will be discussed separately.

The confined middle layers show hardness exceeding the SMCL prescribed by EPA. Furthermore, the dissolved solids content exceeded the SMCL of 500 mg/L in 90 percent of the wells.

The sodium content in the southern, confined aquifers exceeds the SMCL of 270 mg/L in about 60 percent of the wells. Fluoride content is generally low, although it is elevated in southern aquifers and exceeded the maximum in 17 percent of the wells. Chloride and sulphate content generally do not exceed SMCL.

Locally high fluoride levels in the Patapsco well of the Rumbly and Frenchtown systems has led to their scheduled abandonment and connection to the Fairmount system [21C].

The limited sample represented by the 23 confined wells in Maryland covered in NAWQA generally confirm the information and conclusions stated in the earlier 1989 USGS study [2]. Six wells, primarily in Wicomico, Worcester County, 1 in Kent, and 2 in

Cecil county show a pH well below the 6.5 standard (SMCL) for drinking water, indicating high acidity. Furthermore, several wells throughout the area show excessive hardness (measured as calcium carbonate) and several wells, particularly in Wicomico and Worcester counties, show high iron content. The earlier USGS report [2] also shows that iron appears to be the most widespread contaminant in the study area.

A 1984 USGS Report [10] on the shallow Columbia aquifer states that, in general, it does not contain highly soluble minerals and that the concentration of dissolved solids is low. However, the water is naturally acidic (low pH). Furthermore, the study emphasizes that concentrations of chemical constituents in the aquifer seem related to the hydrogeological characteristics of the area from which the samples are taken. The summary statistics of the concentrations of selected chemical constituents in the Columbia aquifer is shown in Table 7 [15]. The significance of variations in different parts of the study area are shown in Table 8 [15].

Data on trace metals are rather scarce. It is generally found that iron levels are naturally high, exceeding the SMCL of 300 microgram/L in more than half the wells. This result may be biased since the highest density of wells sampled tended to be urban areas. The Wicomico County Health Department reported a median of 410 microgram/L in 56 percent of the wells, throughout

Table 7 --Summary statistics of concentrations of selected chemical constituents in water of the Columbia aquifer

Constituent	Number of samples	Minimum	25th percentile	Median	75th percentile	Maximum
pH[1]	192	3.8	5.1	5.6	6.2	7.8
Specific conductance,[1] umho/cm	192	18	88	142	219	716
Calcium, mg/L as Ca	151	0	3.1	5.7	9.6	63
Magnesium, mg/L as Mg	168	0	1.0	2.5	5.6	20
Sodium, mg/L as Na	151	2.2	5.4	7.5	11	140
Potassium, mg/L as K	151	<0.1	1.1	2.1	3.3	31
Bicarbonate,[1] mg/L as HCO_3	89	0	4	8	22	170
Sulfate, mg/L as SO_4	151	0	1	3	9	140
Chloride, mg/L as Cl	181	1.2	6.7	9.4	15	75
Nitrate plus nitrite, mg/L as N	509	<0.01	0.2	3.5	7.8	58
Dissolved iron, mg/L as Fe	150	<0.003	0.010	0.047	0.468	14.0
Silica, mg/L as SiO_2	149	6.8	13	17	25	51

[1] Measured in the field.

Table 8 —Comparison of concentration of chemicl constituents in different parts of the study area

[Kruskal-Wallis test result is the percent probability that differences between the two areas are due to chance.]

Constituent	Counties				Result of Kruskal-Wallis test
	Caroline and Dorchester		Wicomico and Worcester		
	Number of samples	Median	Number of samples	Median	Probability
pH[1]	112	5.5	62	5.6	1.8
Specific conductance,[1] umho/cm	112	143	62	141	64.0
Calcium, mg/L as Ca	80	5.6	53	6.5	36.0
Magnesium, mg/L as Mg	89	3.2	62	2.1	.13
Sodium, mg/L as Na	80	5.8	53	11.0	.01
Potassium, mg/L as K	80	2.8	53	1.2	.01
Bicarbonate,[1] mg/L as HCO_3	53	5.0	33	19.0	.01
Sulfate, mg/L as SO_4	80	2.5	53	5.0	.20
Chloride, mg/L as Cl	104	9.0	58	11.0	4.8
Nitrate plus nitrite, mg/L as N	170	4.5	121	2.2	.22
Silica, mg/L as SiO_2	79	14.0	52	25.0	.01
Iron, dissolved, mg/L as Fe	79	.026	53	.190	1.26

[1] Measured in the field.

the county, exceeded the SMCL. Excess iron can cause brownish discoloration of plumbing fixtures, cooking utensils and laundered goods. In high concentrations it could impart a bitter or stringent taste to the water.

Manganese is frequently found in conjunction with iron. More than 60 percent of the surficial wells exceeded the 50 microgram/L SMCL. Some zinc levels can be found elevated locally, generally caused by galvanized piping or casing.

In urban areas, where elevated iron and manganese levels are likely to be found in surficial aquifers, or when withdrawing from deep aquifers water treatment plans, associated with central water distribution systems generally remove the offensive trace elements. Water treatment systems in rural communities can also effectively remove iron. It can also be removed by home treatment systems, if levels are not too excessive [31C].

Data on organic constituents of water withdrawn from confined aquifers is very scarce.

Nitrates

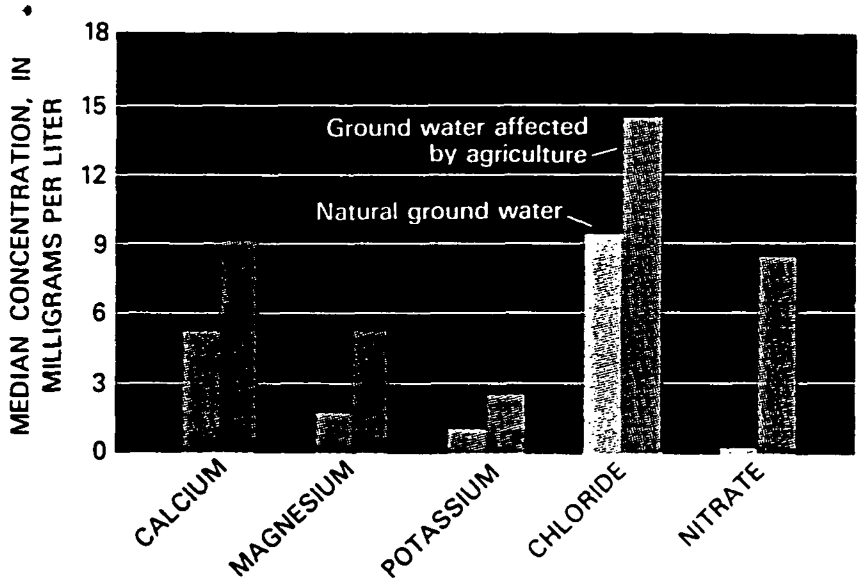
The major constituent in water recovered from water-table aquifers in agricultural areas is the presence of nitrates resulting from the use of inorganic fertilizers and manure. The contribution of agriculturally-sourced constituents to water is shown in Fig 7 from the NAWQA study [8].

The agricultural sector on the Eastern Shore underwent a major transition in the 50's and 60's [32]. It was previously dominated by fruit and dairy farms. But as a result of rising labor conditions this type of farming has been largely changed to poultry and grain production to support the economy. This change has resulted in greatly increased corn and soybean production, which accounts for 40% of the state's crops [61].

Corn is a heavy user of nutrients, about 1 pound of nitrogen for every bushel of corn [32]. Excess nitrates, being very soluble, find their way into shallow water, and occur in both surface water and unconfined aquifers [2].

As shown in Figure 8 [2], the nitrate concentration in the surficial aquifers varies widely with the depth of wells. Furthermore, nitrate concentration is low in low density residential areas and highest in agricultural areas associated with poultry production and corn and soybean growth.

The NAWQA study [8] confirms that nitrate concentrations are elevated in the watertable aquifers in the northern half and in the southern tip (Virginia) of the peninsula, particularly



MAJOR CONSTITUENTS IN WATER IN THE WATER-TABLE AQUIFER IN AGRICULTURAL AREAS ARE NITRATE FROM INORGANIC FERTILIZERS AND MANURE, CALCIUM AND MAGNESIUM FROM LIMING, AND POTASSIUM AND CHLORIDE FROM POTASH.

Figure 7.

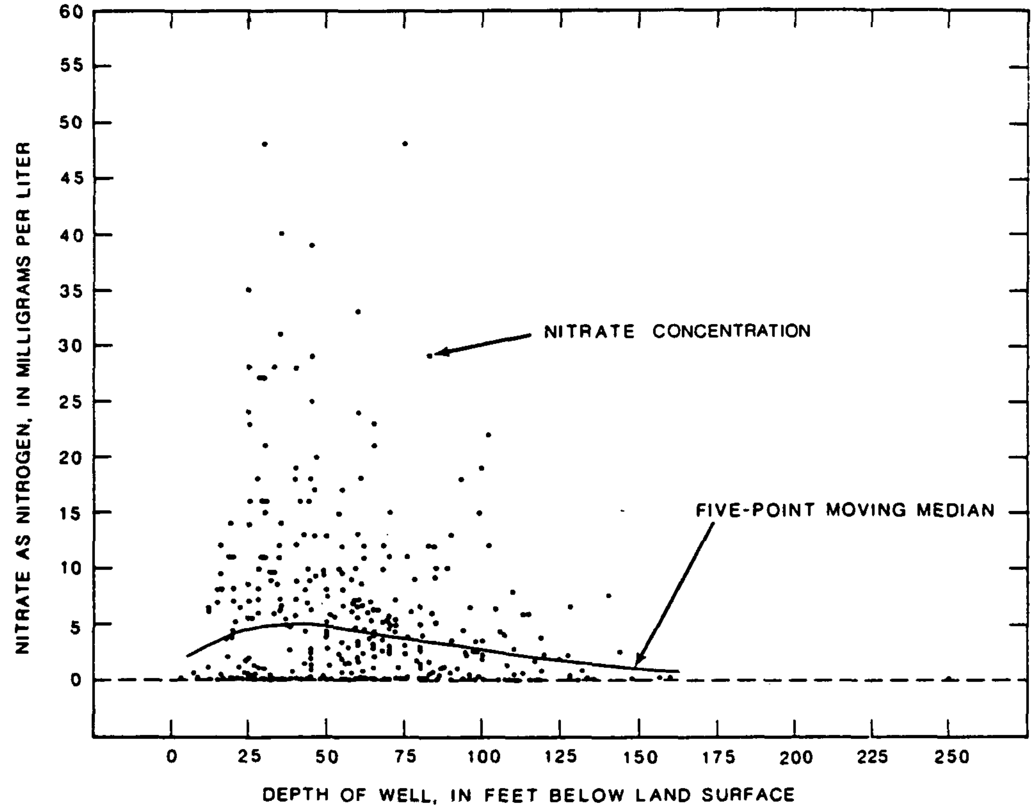
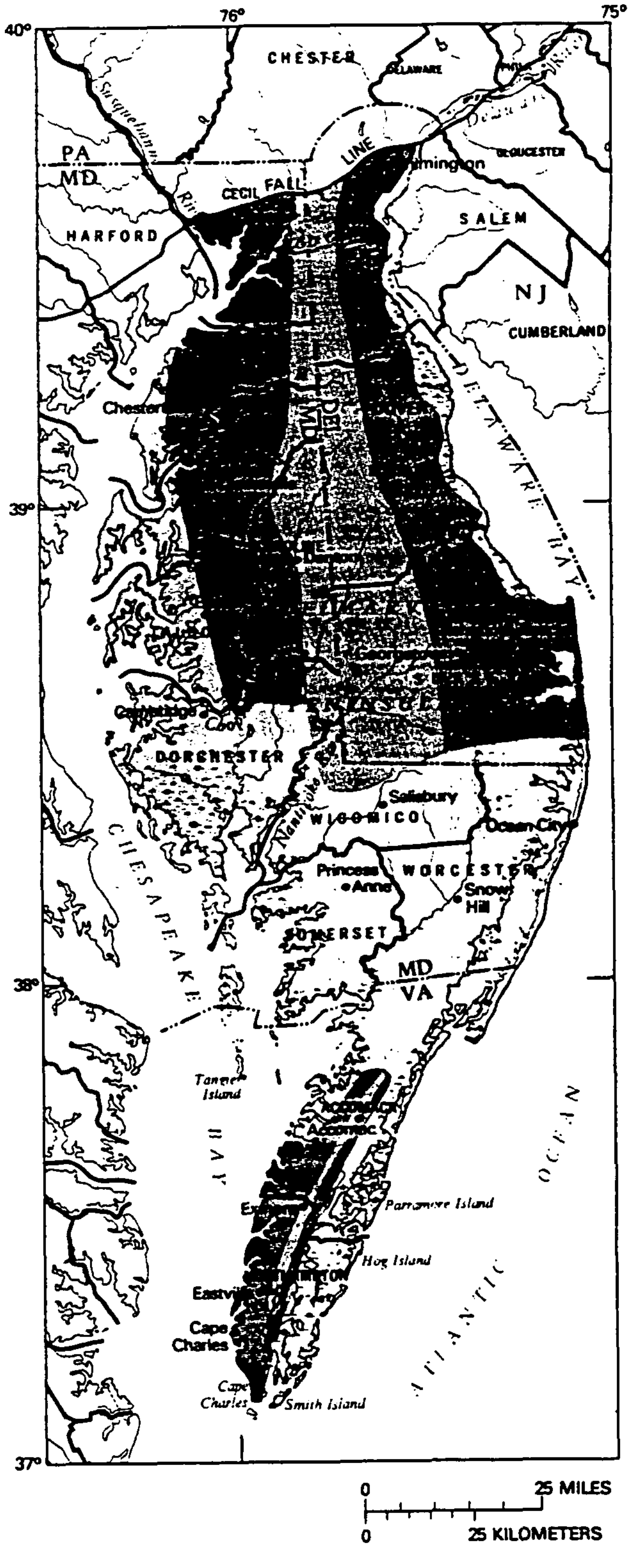


Figure 8 —Nitrate concentrations with depth of wells (compiled from U.S. Geological Survey data).

Figure 8.

in areas that flank the central upland. Nitrates are not commonly detected in the underlying confined aquifers. Fig 9 from the NAWQA study [8] shows the distribution of nitrate concentration on the Delmarva Peninsula. It should also be noted that the high nitrate concentration in ground water contributes to the overall nitrogen loading to the Chesapeake Bay.



EXPLANATION

NITRATE CONCENTRATIONS VARY REGIONALLY, DEPENDING ON FACTORS SUCH AS GEOLOGY, SOILS, LAND USE, AND HYDROLOGY

- (blank box) AREA WITH LITTLE NITRATE
- (stippled box) AREA WITH DETECTABLE CONCENTRATIONS OF NITRATE, GENERALLY LESS THAN 10 MILLIGRAMS PER LITER
- (black box) AREA WITH DETECTABLE CONCENTRATIONS OF NITRATE, COMMONLY NEAR OR EXCEEDING 10 MILLIGRAMS PER LITER

Figure 9.

Wellhead Protection Program

The State of Maryland has a well designed Wellhead Protection Program (WHPP), which is the responsibility of the Water Management Administration of the Maryland DOE. It was initiated in 1991 [..] in response to a joint resolution of the Maryland General Assembly for the purpose of protecting ground water sources from numerous sources of contamination. The program involves coordination among several state and federal agencies, as well as local governments and agencies. A report is submitted to the General Assembly annually [31-35]. It was beyond the scope of this analysis to examine the effectiveness of this program. This current study examines only the current ground water conditions and projected usage, on the assumption that WHPP is completely effective and, consequently, that the quality of ground water would not deteriorate.

Assurance of the quality and quantity of current water supply is maintained through the Maryland Ground Water Protection Program, which was developed by the Maryland DOE. Although it includes the water appropriation and use permit system of DNR, the plan is dominated by ground water protection programs administered by DOE, such as the WHPP and the Underground Storage Tank Program.

The Water Appropriations Act is administered by the Water

Resources Administration of the DNR, in coordination with other state agencies. This process requires issuances of permits which specify the amount of water to be withdrawn, the location of the well, the formation to be used and the duration of the permit. It is based on the "reasonable use" doctrine. The amount of water has to be reasonable for the proposed use and the impacts on the resource and other users of the resource must also be "reasonable"[21C].

SALT WATER INTRUSION

As a result of both intense development and the potential of further development, two areas are being highlighted in which salt water intrusion of the ground water supply is likely to be a serious problem. In the Kent Island area of Queen Anne's County salt water intrusion has already occurred. In the Ocean City area the potential of salt water intrusion as a result of increasing withdrawal was further investigated.

Kent Island Area

The Kent Island area has undergone considerable development, and is expected to continue to do so, resulting in continual increasing demand for fresh water. Virtually all the fresh water is currently obtained from ground water in the Aquia aquifer [15]. This aquifer is relatively shallow and dependable. However, its water level has dropped from several feet above sea level in the mid-1950's to several feet below sea level in 1984.

As a result Kent Island has experienced high chloride levels caused by brackish water entering the widely used Aquia aquifer. The route of the brackish water is through an underground connection created by an ancient buried channel of the Susquehanna River.

The Maryland Geological Survey conducted a 3-year study, published in 1988 [15], primarily of the hydrogeology of the Aquia aquifer in the Kent Island area. It was known that brackish water is present in the Aquia aquifer along the Chesapeake Bay shore from the northernmost tip of the island (Love Point) to at least as far south as Prices Creek [15]. In the northern part of the brackish water zone, the entire vertical section of the Aquia contains brackish water. In the southern part of the brackish zone, the bottom of the Aquia contains brackish water, but the top contains fresh water. Five major hydrogeological controls that influence the movement of the water were examined.

A "quasi three-dimensional, finite difference two-layer areal flow model" was developed to simulate the response of water levels to projected pumpage in the Aquia aquifer. The results show that the greatest declines occur on the eastern part of the island near Grasonville.

A number of different pumping strategies was simulated. In addition to simulating the current conditions, including projections for the 1985 - 2005 time period, sensitivity analyses were conducted assuming higher and lower pumping rates. The simulated potentiometric surface of the Aquia aquifer for 1990, based on projected pumpage is shown in Fig 10 [15].

One alternative strategy proposed involves replacing all

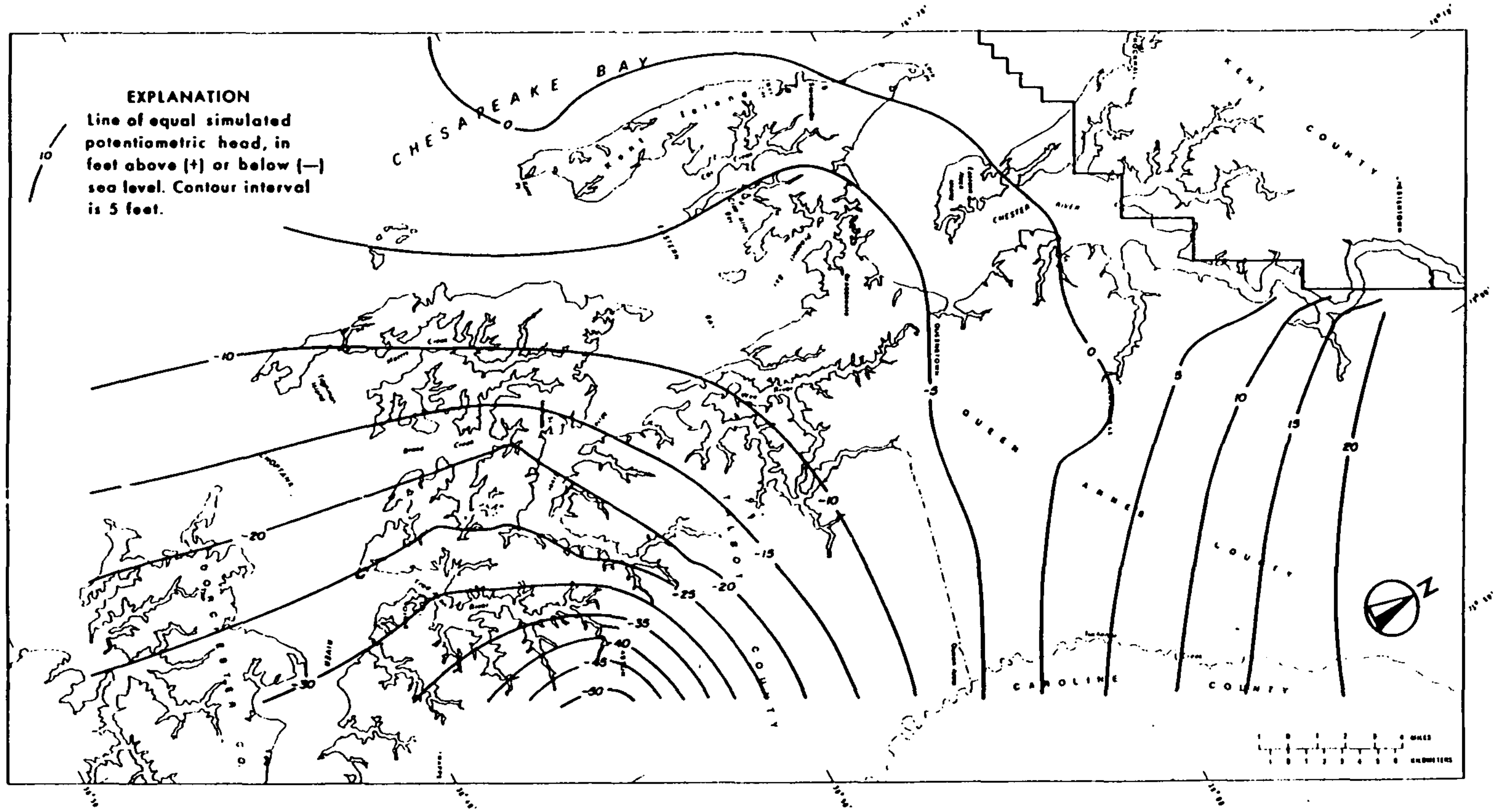


Figure 10— Simulated potentiometric surface of the Aquia aquifer for 1990, based on projected pumpage.

domestic and commercial wells by three production wells in the Aquia aquifer in the Grasonville area and installing a water distribution system. The model shows a large local cone of depression about the production wells. A simulated surface of this strategy projected to 2005 is shown in Fig 11.

Two more strategies involve a central pumping station at Grasonville reaching deeper into the Magothy or Potomac aquifers. In one case one half of the pumpage would be replaced by deep wells and in the other case all of the pumpage would be replaced by deep wells and central treatment and pumping stations. The simulated surface considering these strategies is shown in Figures 12A and 12B respectively. Clearly, the cone of depression shown for the Aquia production pumps disappears. This model did not consider any impact of leakage from the Aquia to the deeper aquifers.

All the simulations show a sharp drop in potentiometric measurements at the Eastern Shore shoreline. This is the result of a deep cone of depression formed by Easton pumping.

A conceptual model of the flow in the Aquia aquifer is shown in Figure 13 [15]. A "cross-sectional solute-transport model" was developed to estimate the movement of brackish water in response to projected pumpage. The results indicate that the fresh water/brackish water interface will move approximately an average

SIMULATION 6

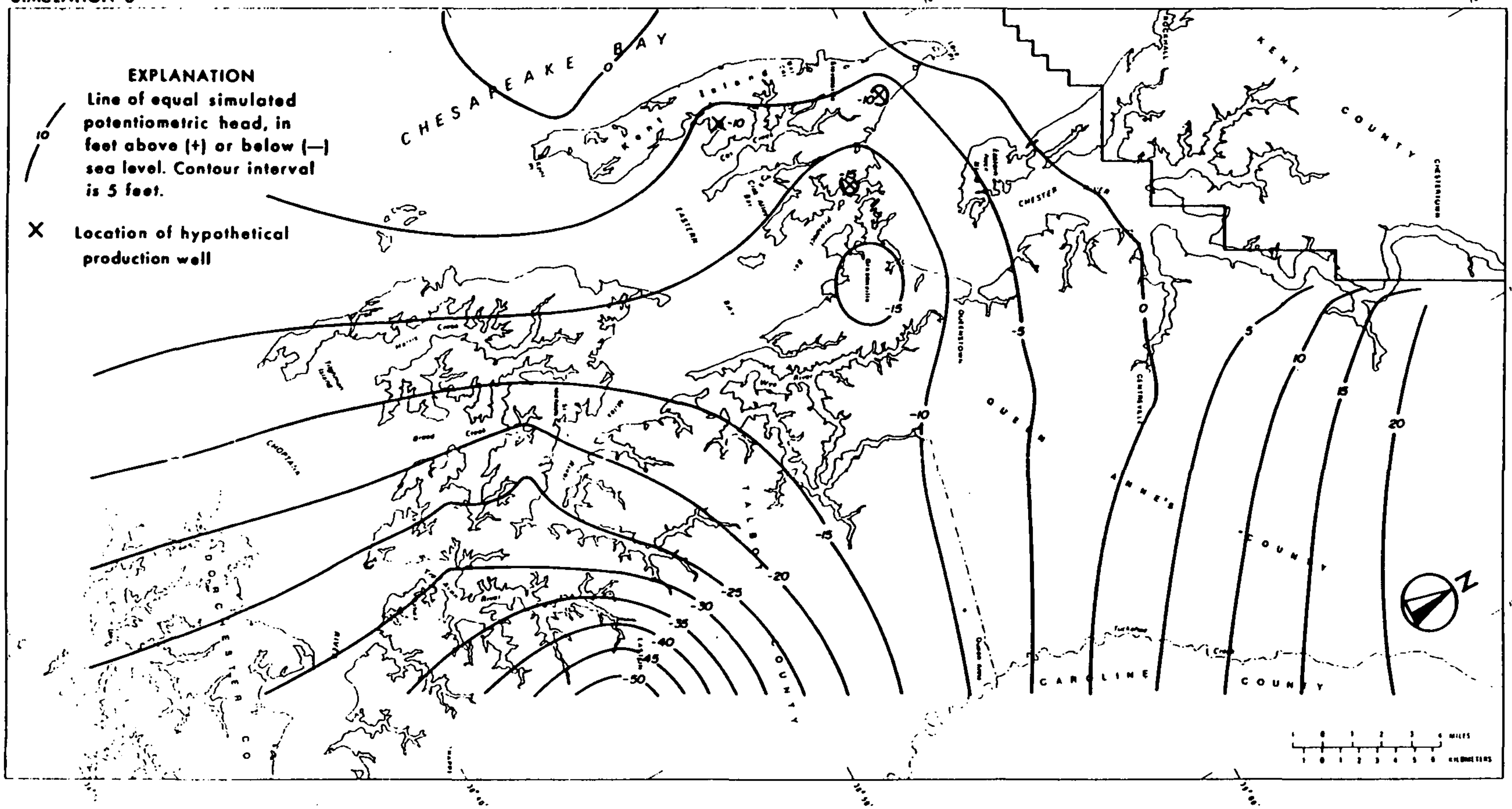


Figure 11 – Simulated potentiometric surface of the Aquia aquifer for 2005, based on the replacement of all projected Kent Island pumpage by three production wells.

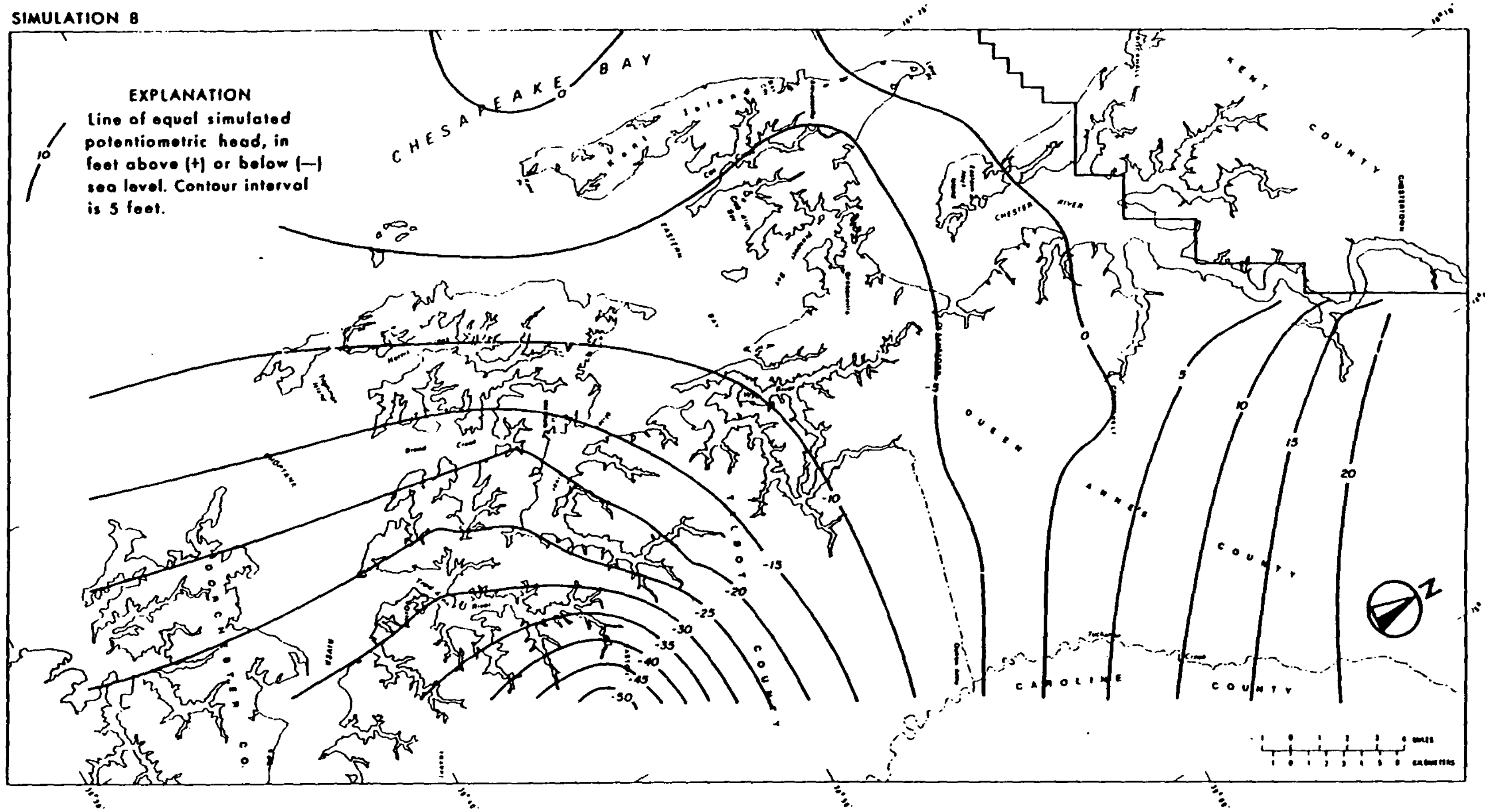


Figure 12A Simulated potentiometric surface of the Aquia aquifer for 2005, based on a 50-percent decrease in projected pumpage at Grasonville.

SIMULATION 9

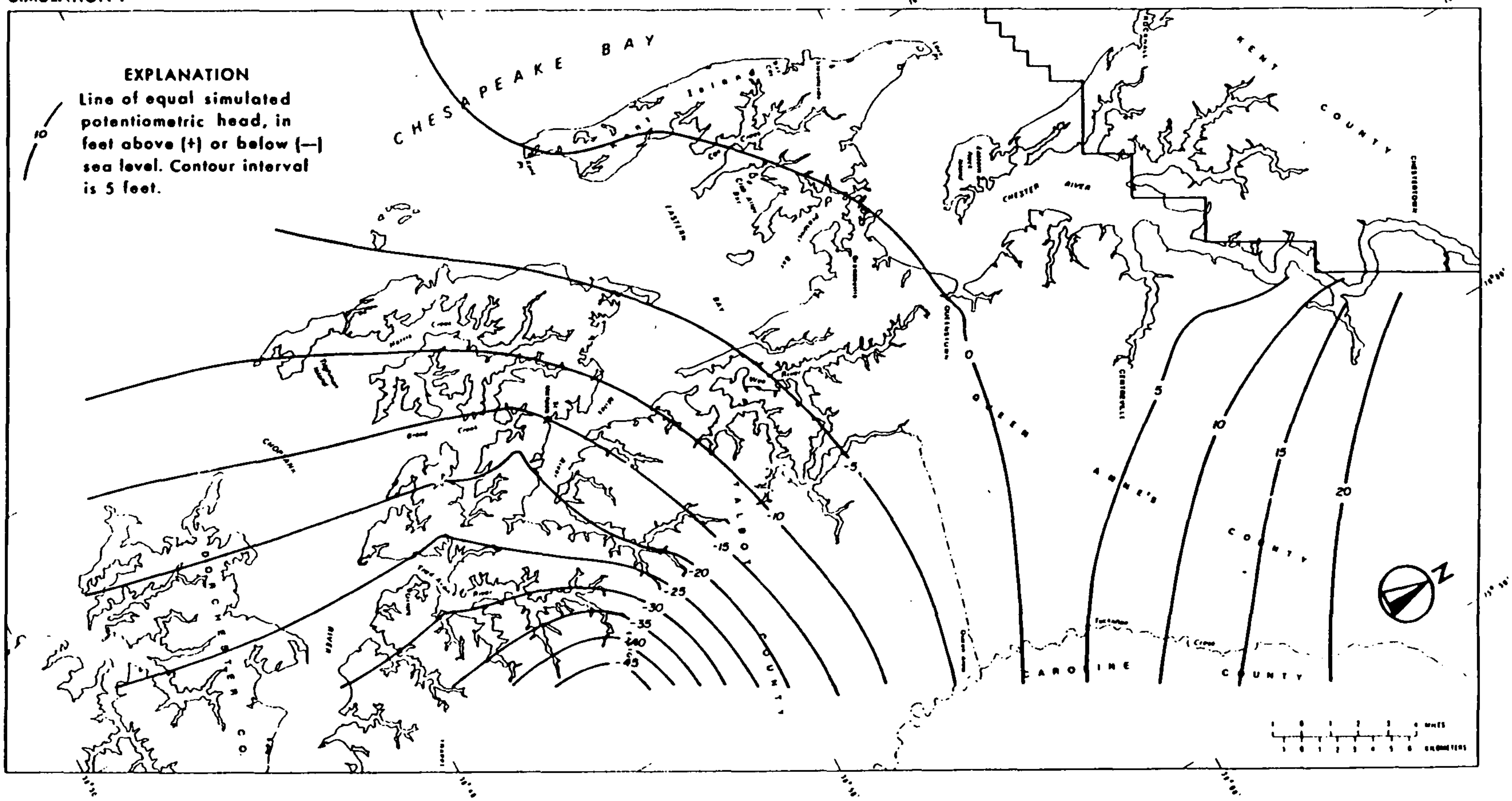


Figure 12B- Simulated potentiometric surface of the Aquia aquifer for 2005, based on discontinued pumpage at Kent Island and Grasonville after 1984.

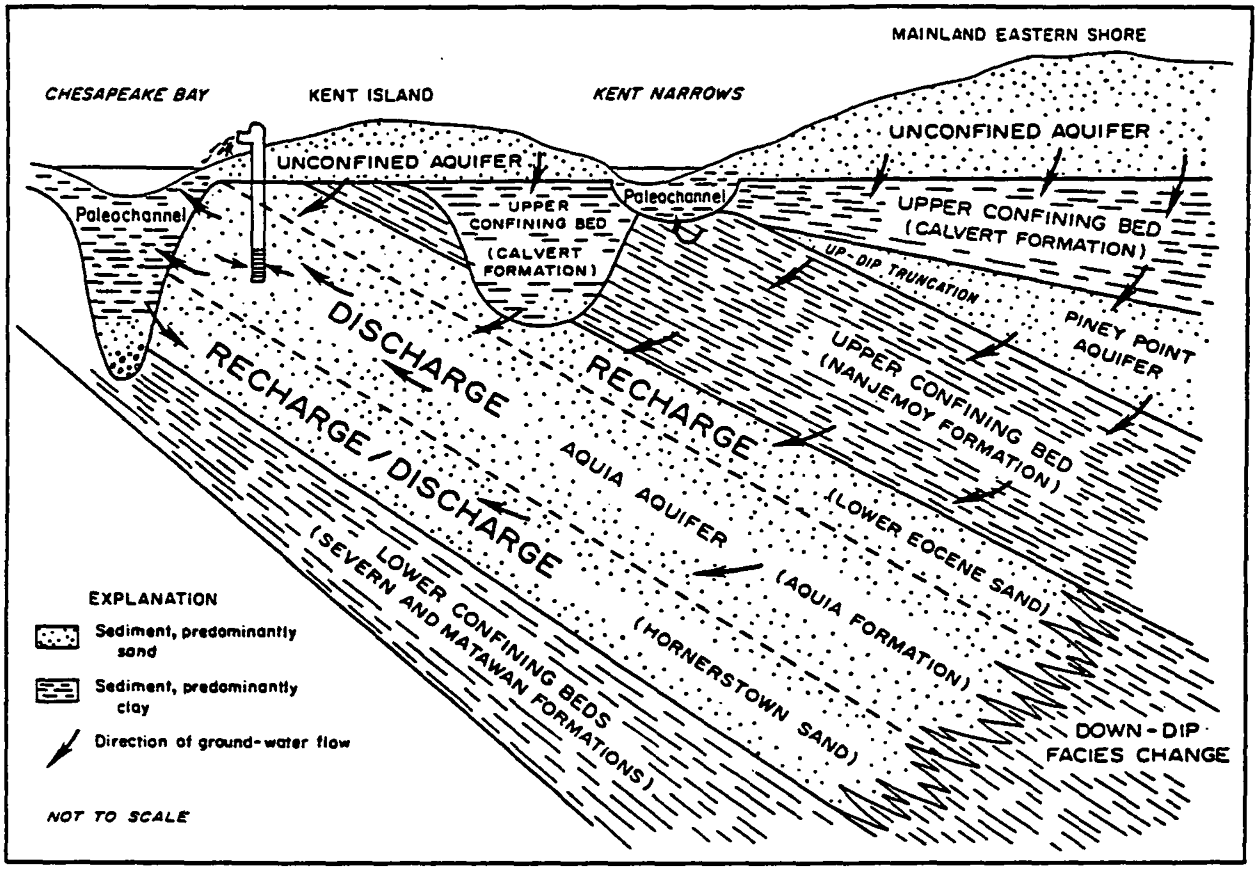


Figure 13. — Conceptual model of the flow system in the Aquia aquifer.

Figure 13.

of 24 feet per year inland based on predicted pumpage. A 20 percent increase or decrease of the pumping rate will alter the interface movement on the average between 21 and 17 feet per year. Cessation of pumping would move the interface 2 feet per year in the opposite direction.

An analysis of the importance of hydrogeological controls on the brackish water movement indicates that density-dependent flow, water pressures in the Aquia aquifer, and the permeability of the upper confining beds are the most important factors.

Another solution was actually implemented. Together, MGS, the Water Resources Administration (WRA) and Queen Anne's County developed a program to eliminate much of the Aquia use and prevent new users from exacerbating the problem [25]. Since 1986, no new users over 1000 gallons per day have been permitted on Kent Island and, since 1989, Queen Anne's County has converted six public systems on Kent Island from Aquia wells to Magothy aquifer wells, as recommended above. During the conversion process, individual homes on wells of poor water quality were added to the public system upon request. Queen Anne's County plans to redirect seven other community systems in the area of highest chloride levels to the Magothy aquifer by 1998. DNR states that recent readings from the chloride monitoring system established by MGS indicate that chloride levels appear to have stabilized as a result of the water management practices [11C2].

Chloride levels are expected to decline as more water users are directed to the Magothy formation [21C].

OCEAN CITY AREA

The greater Ocean City area encompasses the City of Ocean City, West Ocean City, the Isle of Wight, areas along Assawoman Bay and Sinepuxent Bay and areas around Fenwick Island, Delaware. Since these areas draw their water supply from the same set of interconnecting aquifers, they should be considered as a total system. The economic importance of continued development of this area is well recognized.

Water Demands

The population in this area is very cyclical, peaking during the summer vacation months. In the past this lead to recovery of the water sources during the "shoulder" months in Spring and Fall. In recent years the season has lengthened greatly, leading to increased consumption during these months as well as to a much larger year-round population.

The ultimate build-out population has been projected to be about 312,700 peak. Historical maximum capita per day demands indicate a 58 gpd demand. This results in a requirement of 18.1 mgd for the maximum daily demand [51]. DNR states that WRA uses 191.2 gpd per household as a guide to reasonable use [21C].

The peak day water demands for Ocean City from the Whitman Requardt Associates study [51], projected to the year 2015 are shown in Figure 14A to be 18.1 mgd, or roughly twice the needs in 1980). (Figure 14A represents an update of the demand estimates shown in Figure 14B and used in the Corps of Engineers report [41] as well as in the DNR Report [21]). The peak day water demands for Ocean Pines is projected to 2005 in Figure 15 [41] to be 2.5 mgd or two and a half times the need in 1985. A similar projection for West Ocean City to 2000 is shown in Figure 16 [41] to be 3 mgd or three times the need in 1985. The projected water demands for the Fenwick Island area are estimated to be 3.05 mgd for the year 2000.

Studies

A Maryland Geological Survey study in 1982 examined the geohydrology of the fresh-water aquifer system in the vicinity of Ocean City and also included an analysis of the impact of simulated water level changes [18]. A 1992 MGS report updates the earlier study using later data [19].

In 1985 The US Army Corps of Engineers published a report that evaluated the water supply in Northeastern Worcester County, Maryland and Southeastern Sussex County, Delaware as a total system. That report also analyzed the cost and benefit of alternative sources for future water supply to that region [41].

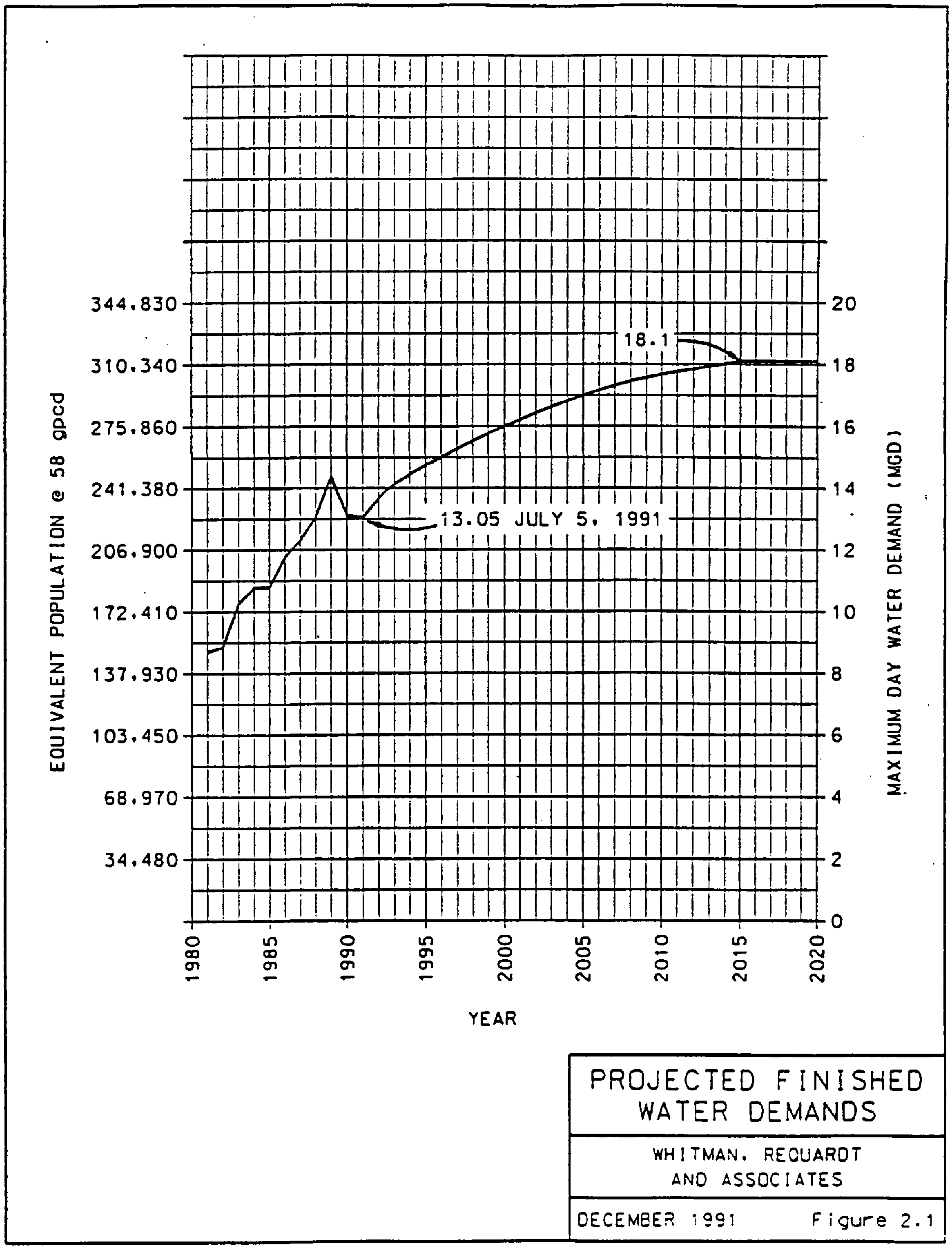


Figure 14A. Peak Day Water Demand Projections for Ocean City (1991)

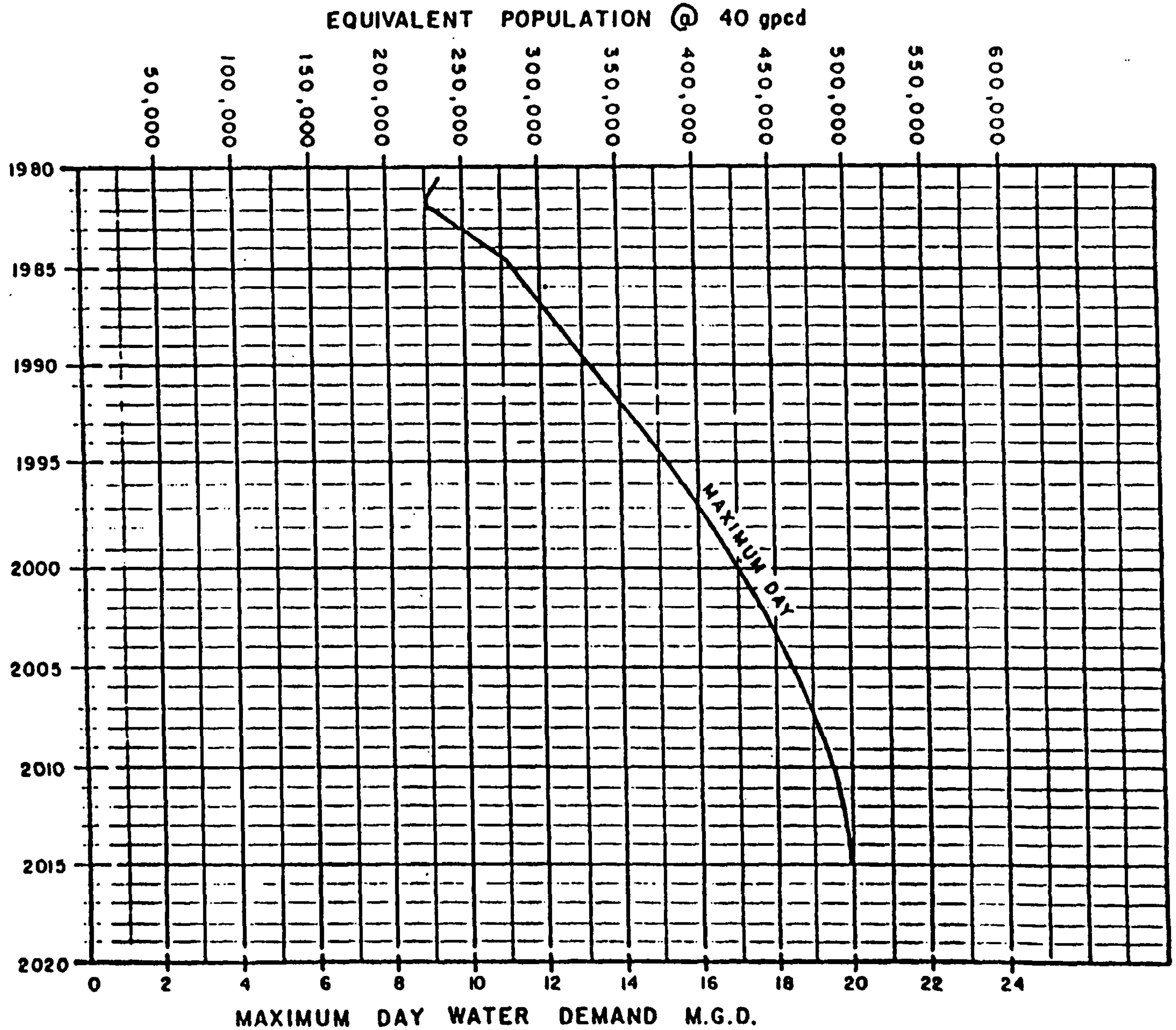


Figure 14B.Peak Day Water Demand Projections for Ocean City

(1985)

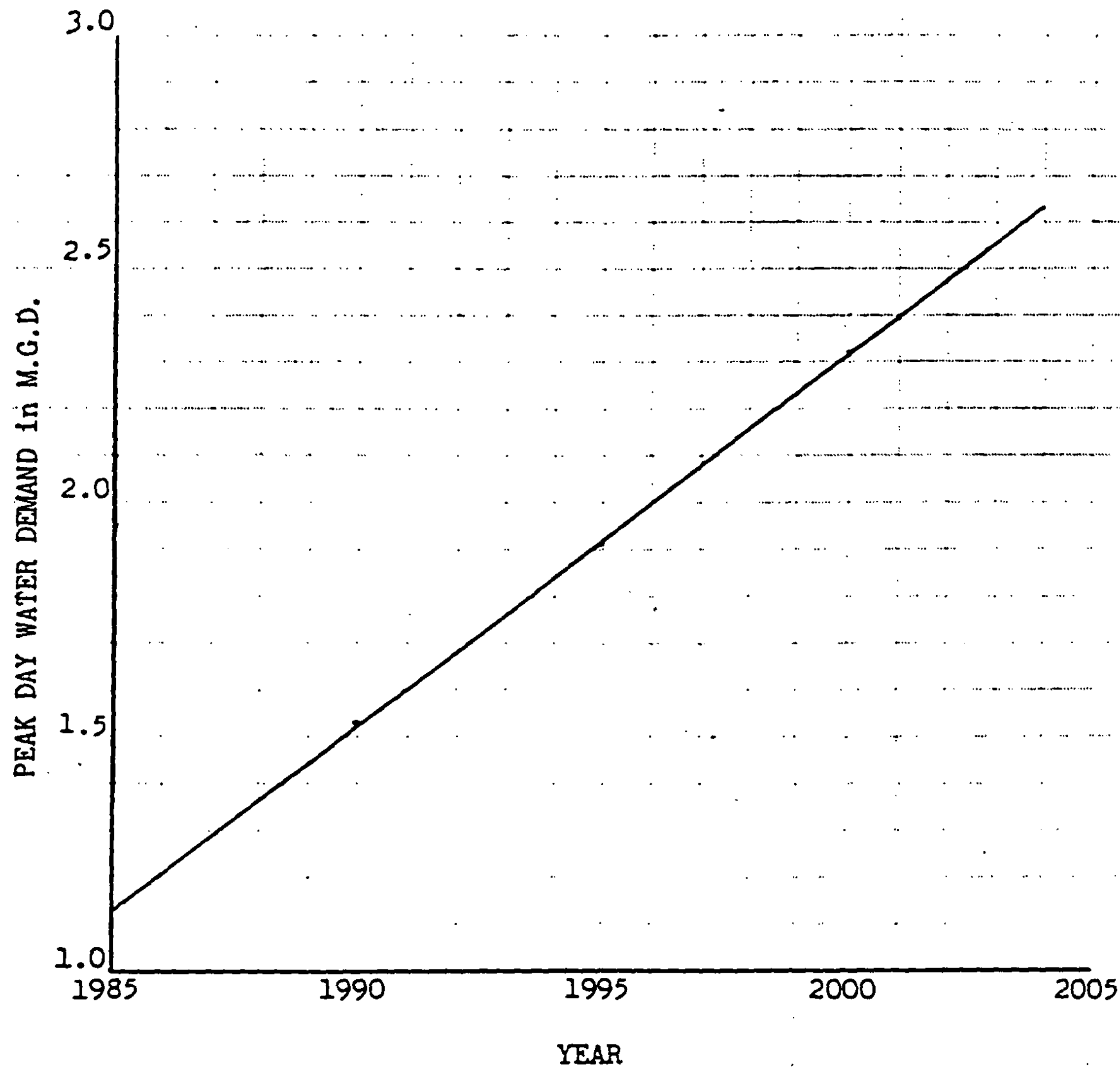


FIGURE 15

PEAK DAY WATER DEMAND PROJECTIONS FOR OCEAN PINES, MD.

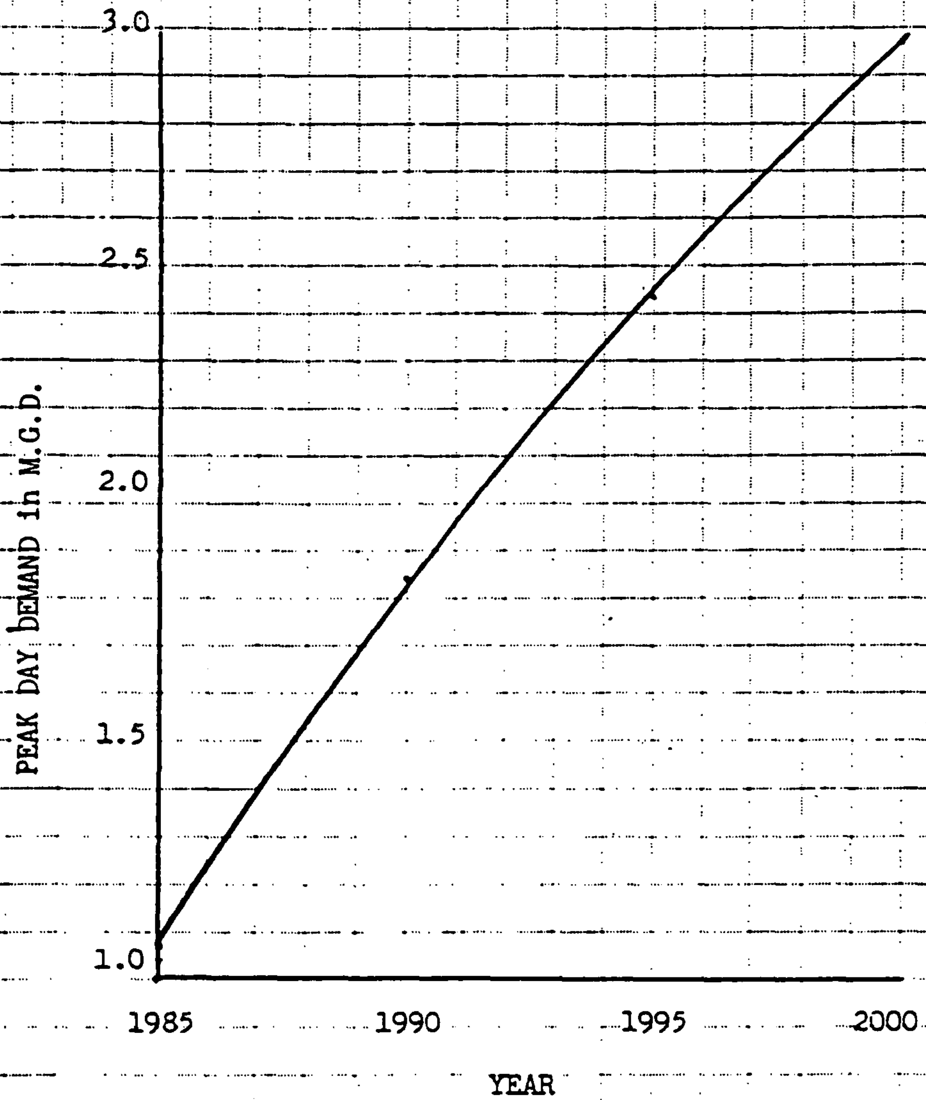


FIGURE 16
PEAK DAY WATER DEMAND PROJECTIONS
FOR WEST OCEAN CITY, MD.

In 1990 the Water Resources Administration of the Maryland Department of Natural Resources, jointly with the Division of Water Resources of the Delaware Department of Natural Resources and Environmental Control, conducted an evaluation of the water supply resources in Northeastern Worcester County and Southeastern Sussex County in Delaware, and developed a Water Supply Resources Development and Management Plan [21]. That study relied heavily on an earlier 1986 Corps of Engineers (Baltimore District) study of Alternatives for Ocean City Maryland and Adjacent Coastal Areas cited above [41].

In 1989 the Town of Ocean City sponsored a well exploration and evaluation report [52] to locate additional sites in the continuing program of spreading out production well sites and to identify and delineate areas of brackish water. Also, estimates of future water movement were made and recommendations to best deal with salt water intrusion were changed from an inland well field to the concept of desalination in Ocean City.

In 1991 the Town of Ocean City sponsored a detailed engineering study and implementation plan [51], updating the 1989 study [52]. This plan could be effected in steps as future needs arise. That plan included provision for additional wells, replacement for aging equipment, additional storage facilities, and improvements as needed. The plan also proposed an interconnected raw water transmission system which would permit control of withdrawal from different wells. Furthermore, that plan included planned phasing of the implementation, the costs and the revenues required.

A 1992 draft report by MGS, prepared in cooperation with the WRA, presents further analyses of the distribution and movement of brackish water in the Ocean City-Manokin aquifer system at Ocean City. By means of models salt water intrusion predictions were made as a function of pumping rates [19].

Water Sources

According to the 1982 Maryland Geological Survey study [18], the fresh water supply in northeastern Worcester County originates in a series of sediments about 450-ft. thick between the land surface and the top of St. Mary's Formation. Water occurs in the Pleistocene aquifer under watertable conditions and in the Pocomoke, Ocean City and Manokin aquifer under confined conditions.

The purpose of the 1982 study was to determine the ground water availability and withdrawal conditions. During periods of great usage (August) a wide cone of depression in the potentiometric surface of the Ocean City and Manokin aquifer results from extensive pumpage. A multilayer aquifer model was calibrated against six years (1971-1976) of historical pumpage and water level data. The model was used to analyze six different withdrawal schemes, keeping the total amount withdrawn constant. The amount to be withdrawn was projected linearly to the year 2000, employing August as the month of maximum withdrawal.

The study concluded that the effectiveness of several confining layers between the Pleistocene and the underlying Manokin aquifer is poor. Consequently, long-continued, large-scale withdrawals from the Manokin aquifer probably would cause vertical leakage from the overlying units, raising the possibility of salt water intrusion from above. The model further indicated that dispersal of pumping centers may widen the drawdown cones and, thereby, reduce the effect of the drawdown.

The study further points out that excessive hydraulic stress in the aquifer system at Ocean City is of special significance because of the presence of salty water in the ocean and bays, the possible occurrence of salt water in the aquifers off shore, and the presence of salty water in the basal part of the Manokin aquifer. Although the Ocean City-Manokin aquifer system was traced seaward for more than 7 miles east of Ocean City, the results were based on off-shore acoustical profiling of sub-bottom sediments in 1977 and do not provide information of the quality of the water in that region.

The 1982 study [18] also examined the western shore water needs, including the Isle of Wight area. A schematic of the aquifers underlying the western shore of the Bays is shown in Figure 17.

The study examined effects of withdrawals from a series of hypothetical pumping sites, again for an August peak condition. The study concluded that satisfying the water needs from either the Manokin or the Pocomoke aquifer will cause water levels to be considerably lower than in the Pleistocene aquifer, causing water to move downward through the confining layers, through discontinuities or permeable areas of the confining beds. One known discontinuity of the confining bed with undetermined shape and extent is located approximately one half mile north of Berlin. The study concludes that salty water, which occurs locally in the Pleistocene aquifer, could enter the Pocomoke aquifer under those head conditions.

It should also be reemphasized that high iron levels persist in the ground water in this area, as shown in Fig 18 [2], as do low pH levels (high acidity). These factors provide further impetus toward the need for additional treatment centers and central water distribution in the area.

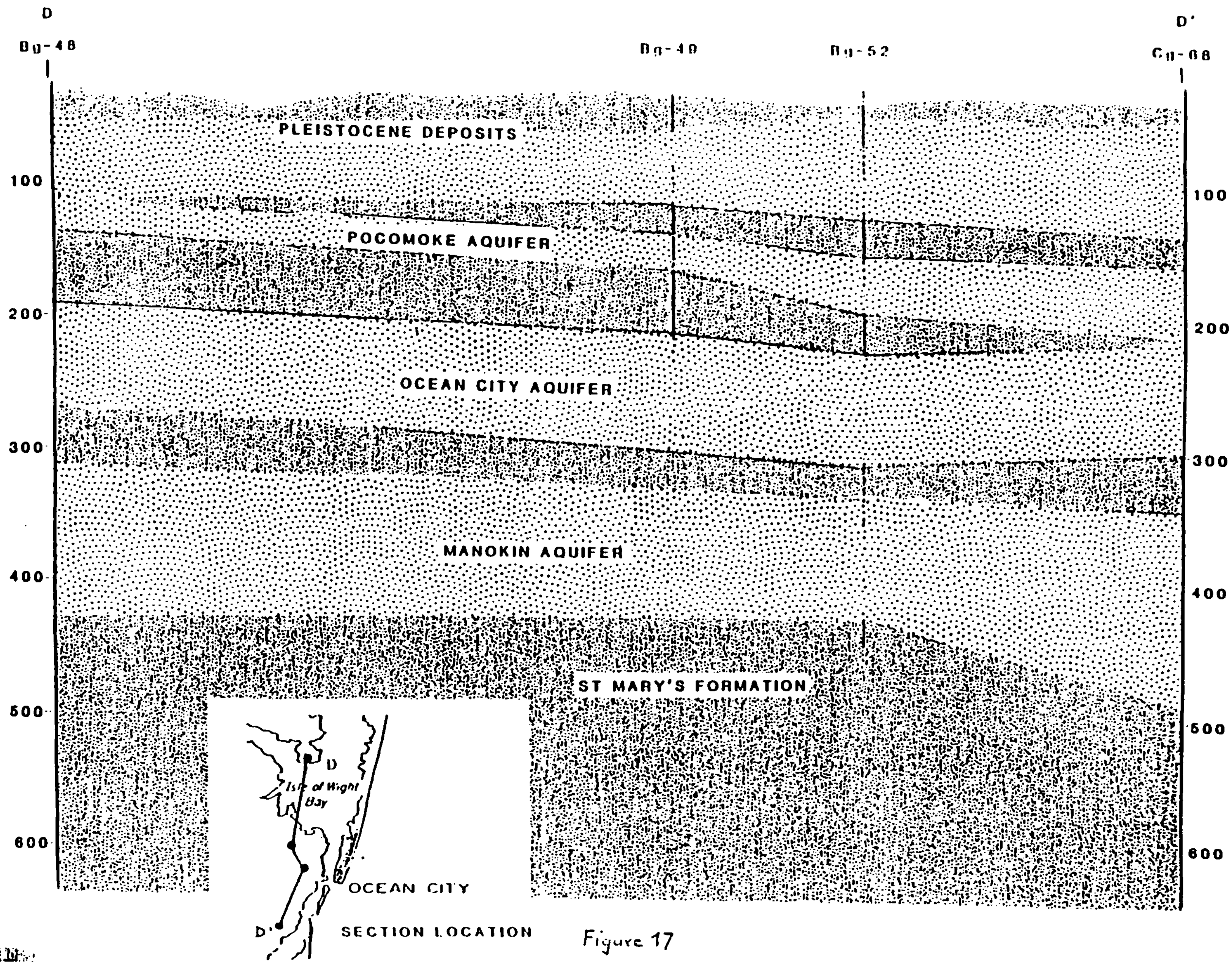


Figure 17

Figure 17.

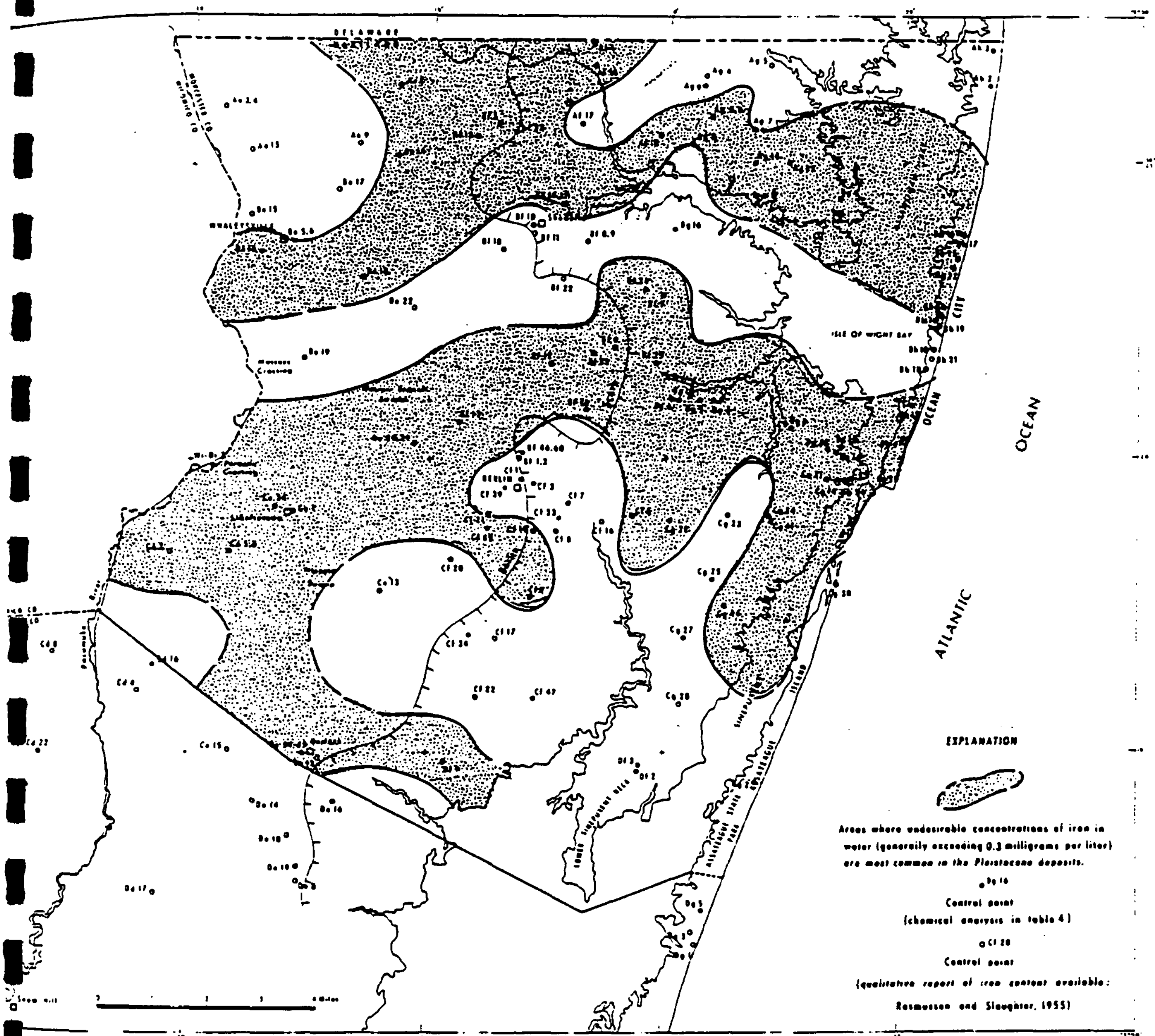


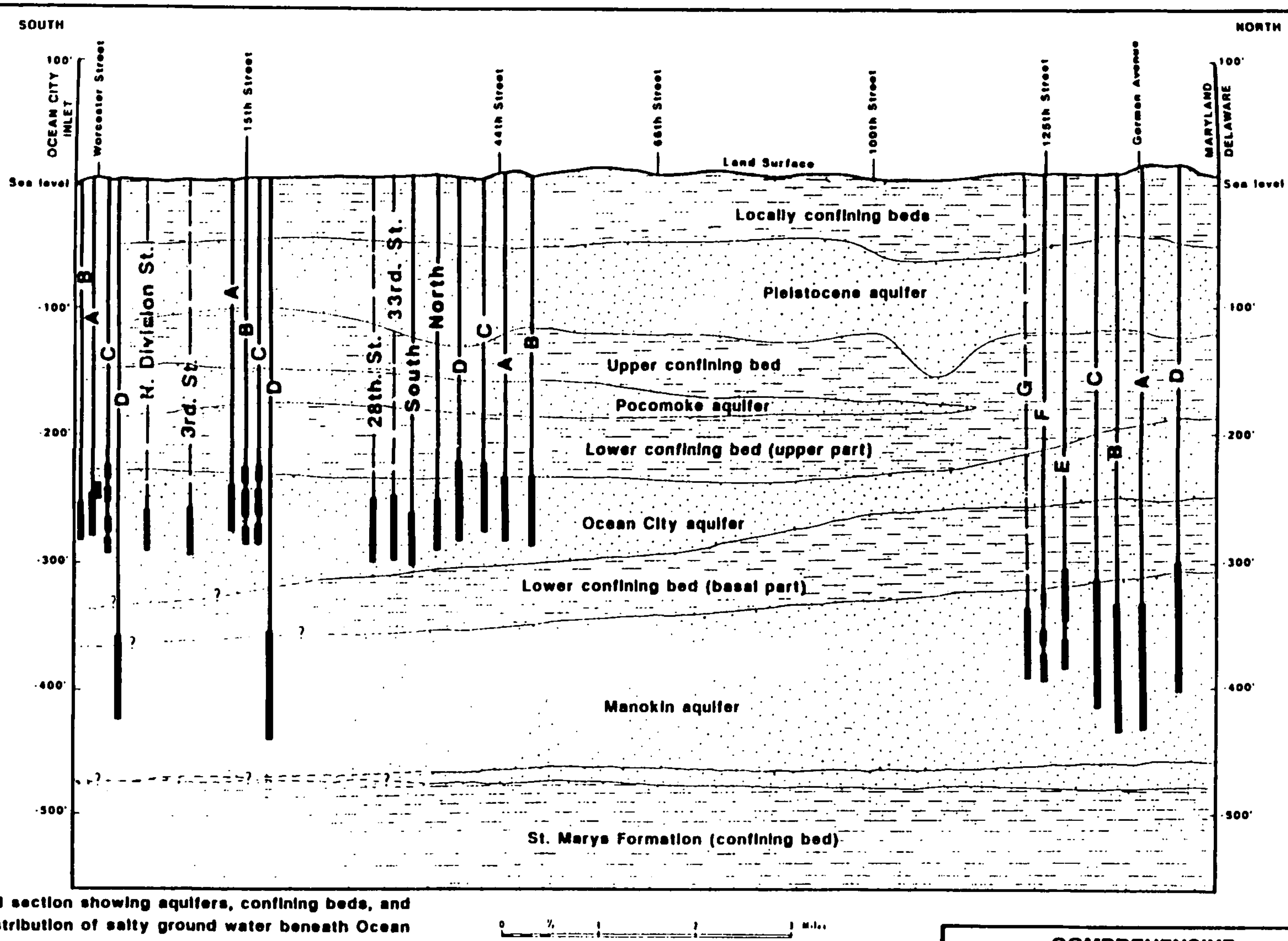
Figure 18 Geographic Distribution of Iron-Rich Water in the Pleistocene Aquifer in Northeastern Worcester County, Maryland (Weigle, 1974).

Current Water Supply

The existing raw water supply in the Town of Ocean City consists of 12 wells in the Ocean City aquifer and 8 wells in the Manokin aquifer. Additionally, another Manokin and 6 Ocean City aquifer wells are in the planning stage. The location of the wells in their respective aquifers is shown in Figure 19 [51].

No other central water supply exists in the greater Ocean City area.

Existing water appropriation, use, and per capita use for large water distribution systems in northeastern Worcester County are shown in Table 9 [21]. The data show high variability in the per capita requirements. WRA uses 191.1 gpd per household as planning measure. These data are comparable to the 58 GPD per person used in the Whitman Requardt estimates [51,52]. It should also be noted that information from the Town of Ocean City [51C] states that 1991 appropriation permits W071G005(03) and W071G105(01) are for 8.0 mgd annual average and 17.6 mgd during the month of maximum use, nearly double that shown in table 9.



Generalized section showing aquifers, confining beds, and vertical distribution of salty ground water beneath Ocean City. (taken from the Maryland Geological Survey, Report of Investigation No. 24)

LEGEND

Ex. Well Casing | Ex. Well Screen | Future Well

EXPLANATION

CONFINING BED clay, silt and fine sand

AQUIFER sand or sand and gravel

WHITMAN, REQUARDT AND ASSOCIATES

COMPREHENSIVE WATER SUPPLY STUDY
TOWN OF OCEAN CITY, MARYLAND

GEOLOGICAL CROSS SECTION AND WELL FIELD

DECEMBER 1991

FIGURE 19

Table 9.

Existing Water Appropriation,Use and Per Captita Use
For Large Water Distribution Systems in Northeastern Worcester County, Maryland

Service Area/ Water Distribution System	Appropriation Permit Number	Average Permitted Appropriation (gpd)	Average Permitted Appropriation During Month of Highest Use (gpd)	1985 Average Daily Use (gpd)	1985 Service Population	Per Capita Water Use 1985 gpd/person
Town of Berlin	WO80G004	250,000	400,000	301,407	1,957	153
Town of Ocean City	WO71G005	4,200,000	9,700,000	3,596,510	76,600 (summer pop.)	100
Ocean Pines/Maryland WO CO Sanitary District	WO68G010	1,000,000	1,667,000	250,572	5,250	48
Riverview Mobile Home Park	WO83G011	24,000	40,000	N/A	54	N/A
Delmarva Trailer Park	WO81G022	8,500	16,500	N/A	249	N/A
Greenridge Trailer Park	WO81G013	3,000	7,000	N/A	N/A	N/A
Ocean City Mobile Home Park	WO68G012	10,000	15,000	3,156	132	28

In general, in the area under consideration the regional flow within the aquifers is in a southeastern direction as shown in Figure 20 [18]. However, heavy seasonal pumping creates large cones of depression in the Ocean City and Manokin aquifers which induce flow toward the pumping centers. Such flow can further induce saltwater intrusion.

Recent chloride concentration data were provided by the USGS [1] for all Ocean City production wells operating in 1991 and which show that the 44th street wells exhibit a dramatic increase in chloride content. The data are shown in Figures 21. This increase resulted in a profile showing the upconing (rise) of the salty boundary as shown in Figure 22 in the Town of Ocean City report [51]. Study of the graph of all the production wells show that the rise in chloride levels have steadily leveled off despiten increased pumpage, except at the 44th street well where the sudden rises in chloride were stabilized by reducing pumpage. However, it should also be observed that the chloride levels of the Manokin aquifer levels were already rather high to start with.

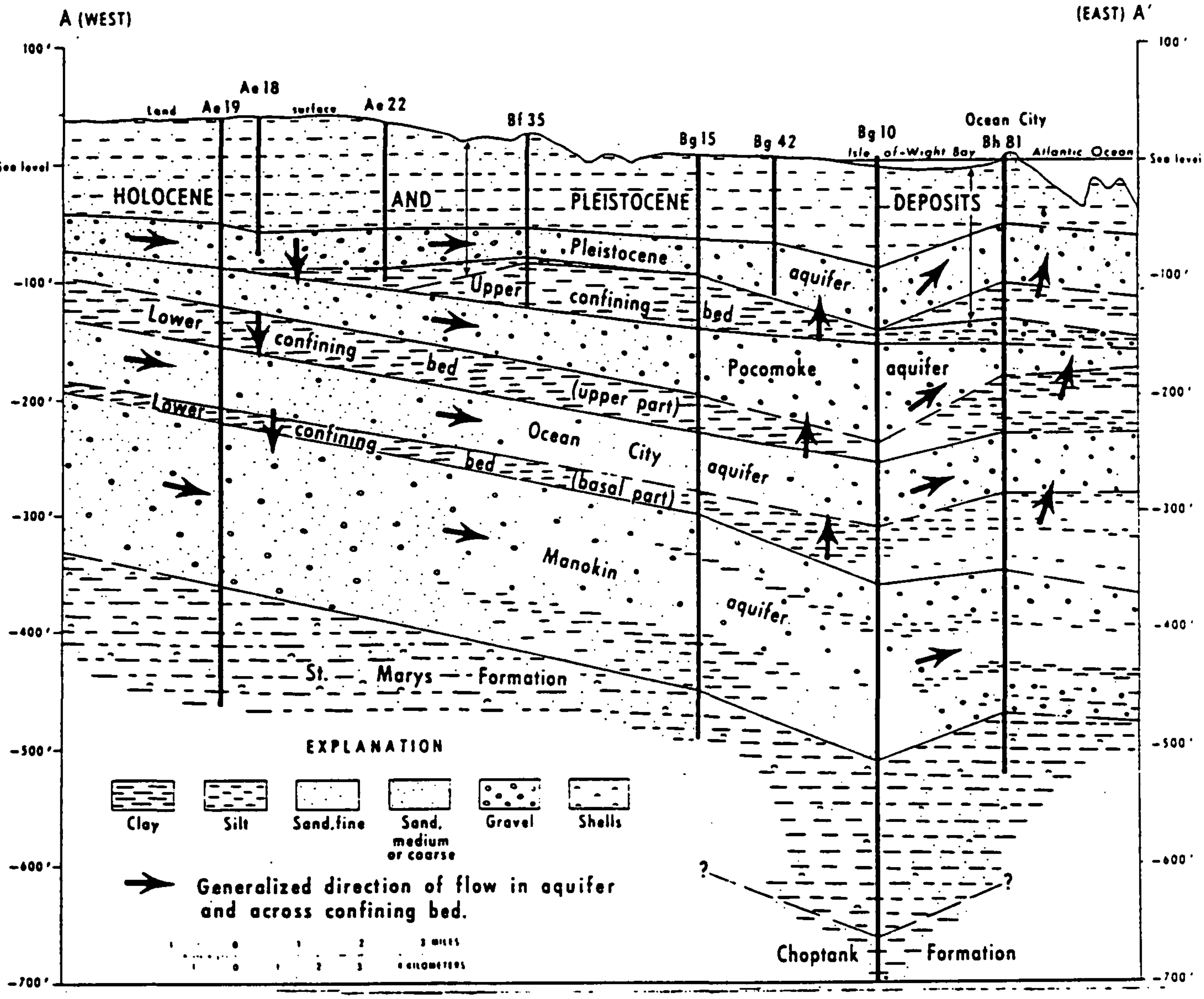
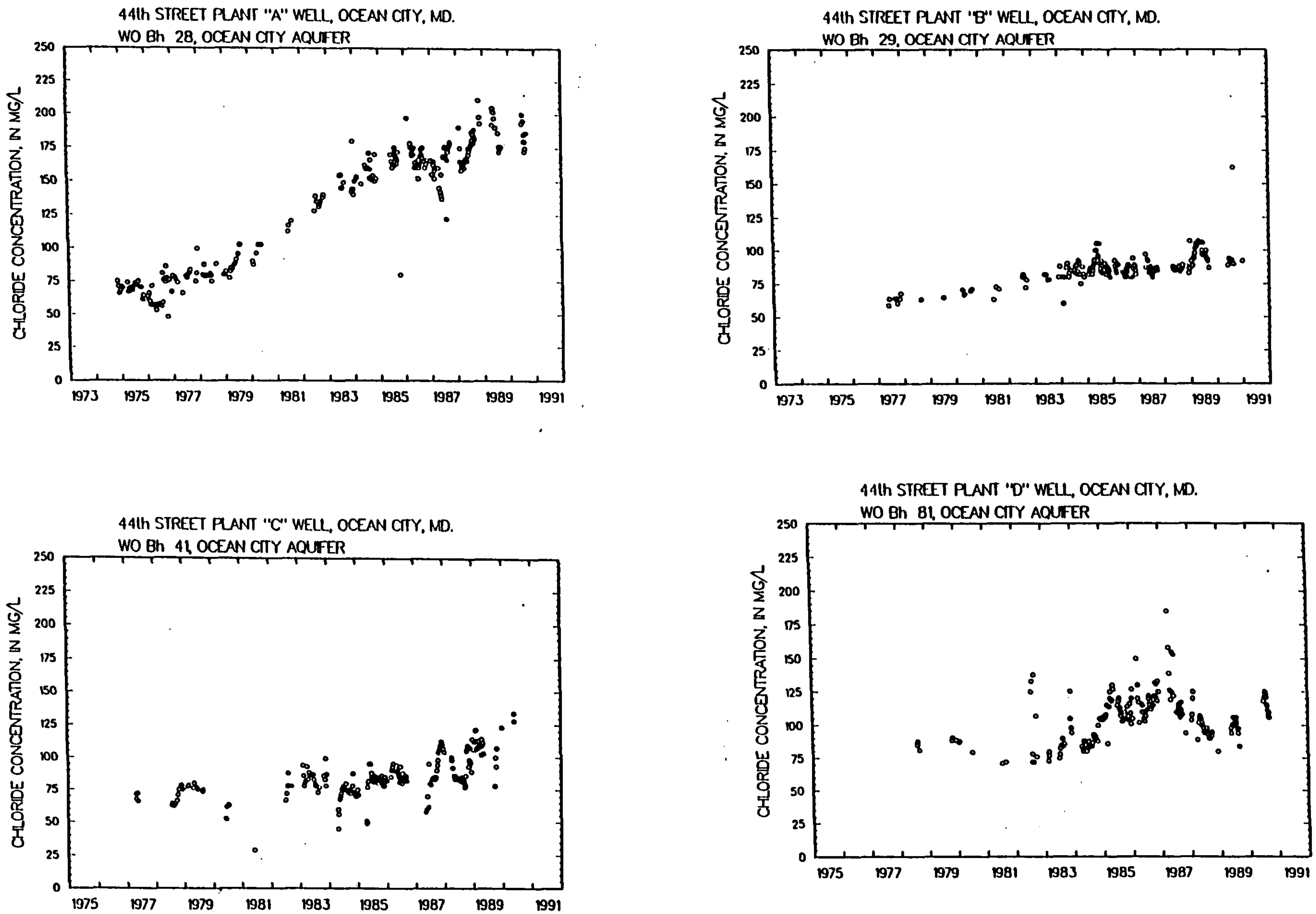
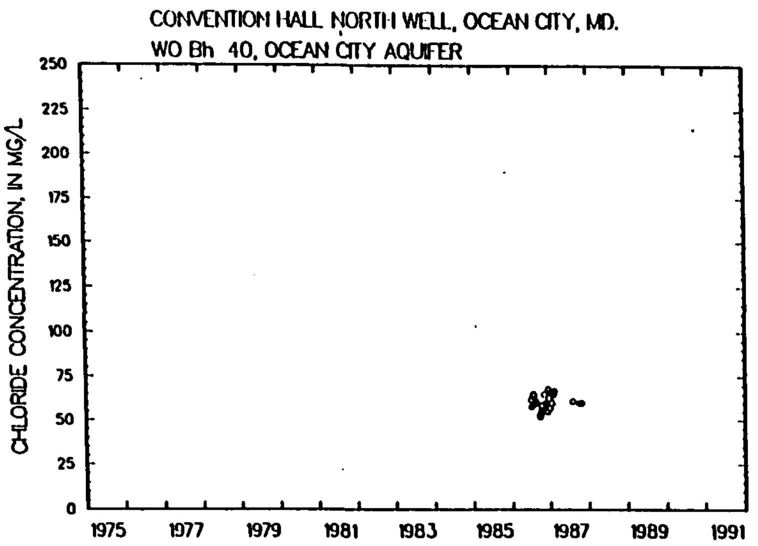


Figure 20 Generalized Geologic Section Trending East-Southeastward across the Planning Area and Generalized Direction of Ground Water Steady-State flow (Weigle and Achmad, 1982).



44th STREET PLANT "A" WELL, OCEAN CITY, MD.
WO Bh 28, OCEAN CITY AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
44th STREET PLANT "B" WELL, OCEAN CITY, MD.
WO Bh 29, OCEAN CITY AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
44th STREET PLANT "C" WELL, OCEAN CITY, MD.
WO Bh 41, OCEAN CITY AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
44th STREET PLANT "D" WELL, OCEAN CITY, MD.
WO Bh 81, OCEAN CITY AQUIFER
CHLORIDE CONCENTRATION, IN MG/L

Figure 21A


CONVENTION HALL NORTH WELL, OCEAN CITY, MD.
WO Bh 40, OCEAN CITY AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
250
225
200
175
150
125
100
75
50
25
0
1975
1977
1979
1981
1983
1985
1987
1989
1991

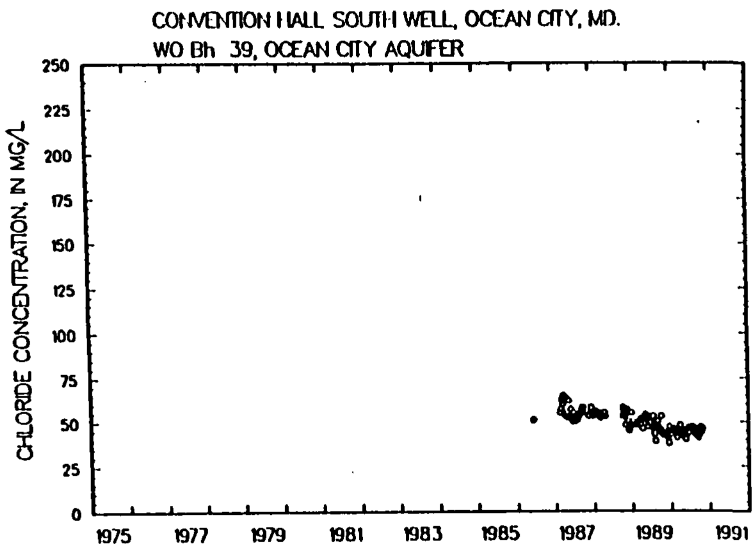
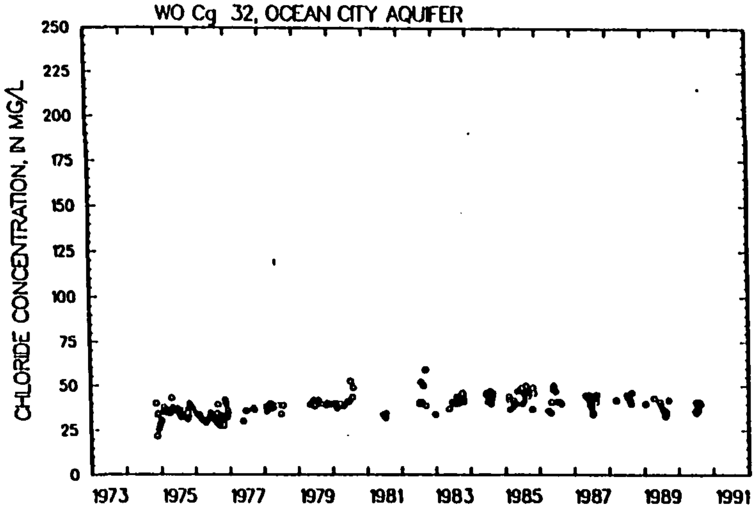
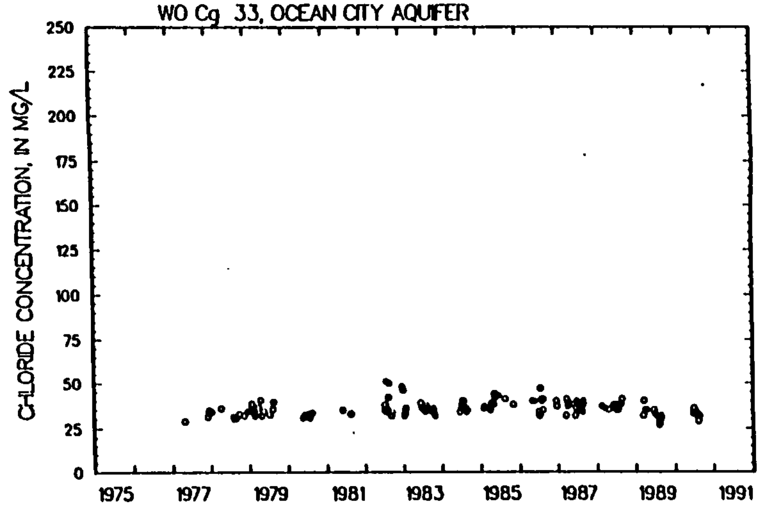

CONVENTION HALL SOUTH WELL, OCEAN CITY, MD.
WO Bh 39, OCEAN CITY AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
250
225
200
175
150
125
100
75
50
25
0
1975
1977
1979
1981
1983
1985
1987
1989
1991

Figure 21B

SOUTH PLANT "A" WELL, OCEAN CITY, MD.
WO Cg 32, OCEAN CITY AQUIFER



SOUTH PLANT "B" WELL, OCEAN CITY, MD.
WO Cg 33, OCEAN CITY AQUIFER



SOUTH PLANT "C" WELL, OCEAN CITY, MD.
WO Cg 34, OCEAN CITY AQUIFER

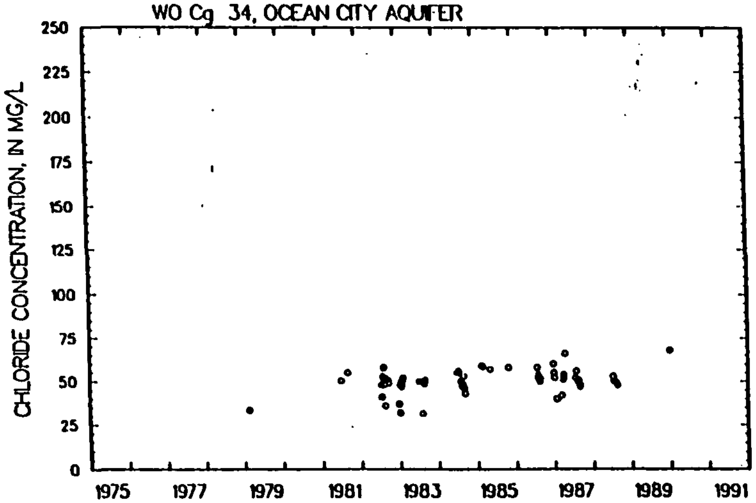
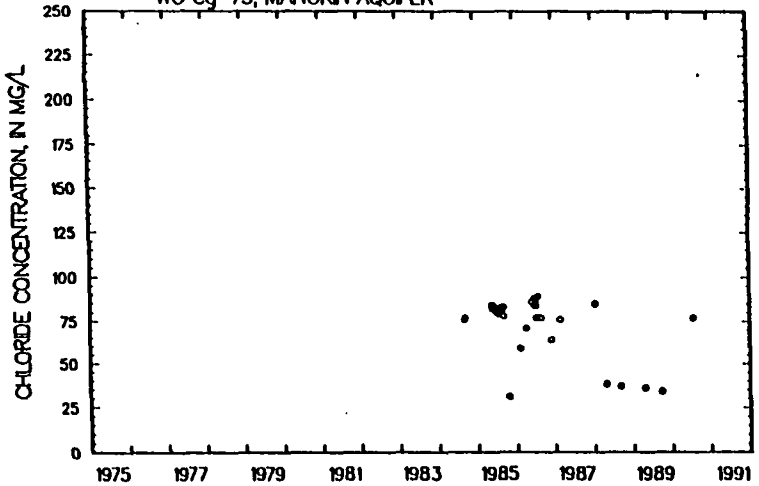
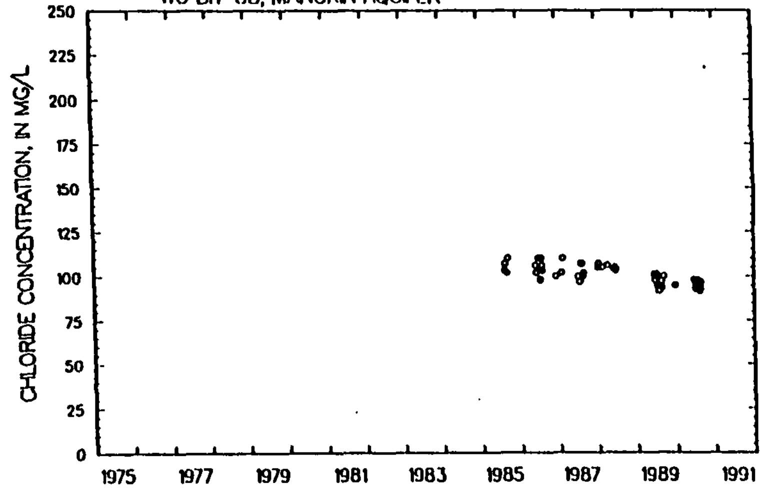


Figure 21C

SOUTH PLANT "D" WELL, OCEAN CITY, MD.
WO Cg 75, MANOKIN AQUIFER



15th STREET PLANT "D" WELL, OCEAN CITY, MD.
WO Bh 88, MANOKIN AQUIFER



130th STREET "E" WELL, OCEAN CITY, MD.
WO Ah 43, MANOKIN AQUIFER

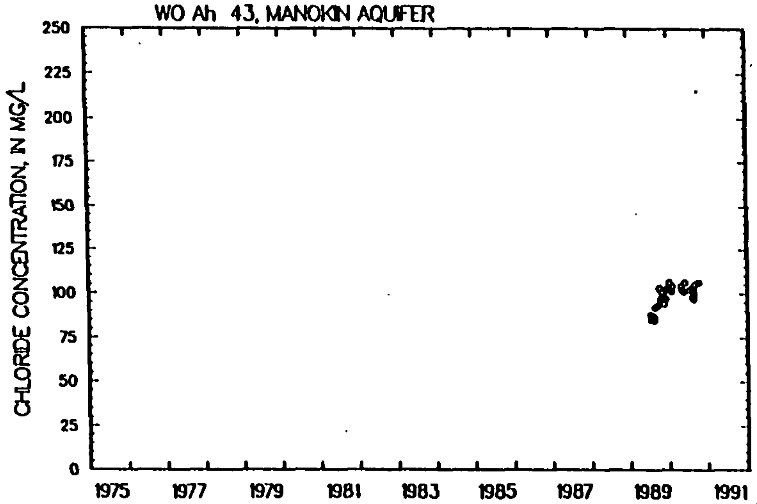
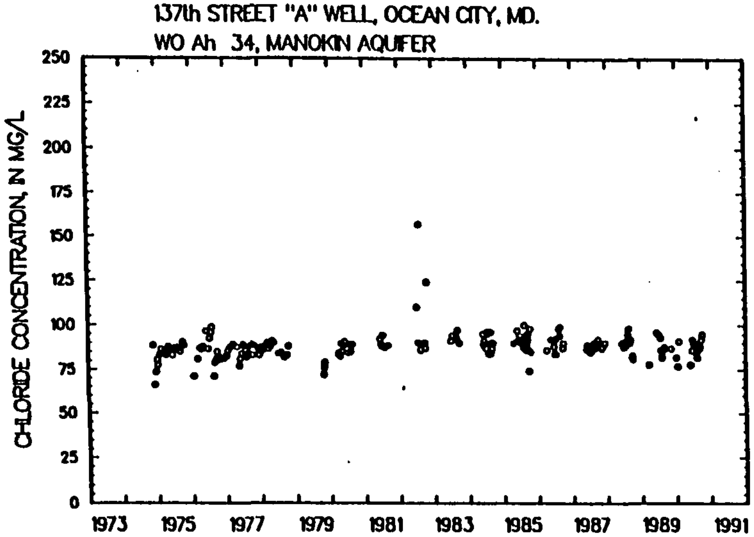


Figure 21D


137th STREET "A" WELL, OCEAN CITY, MD.
WO Ah 34, MANOKIN AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
0
25
50
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1973
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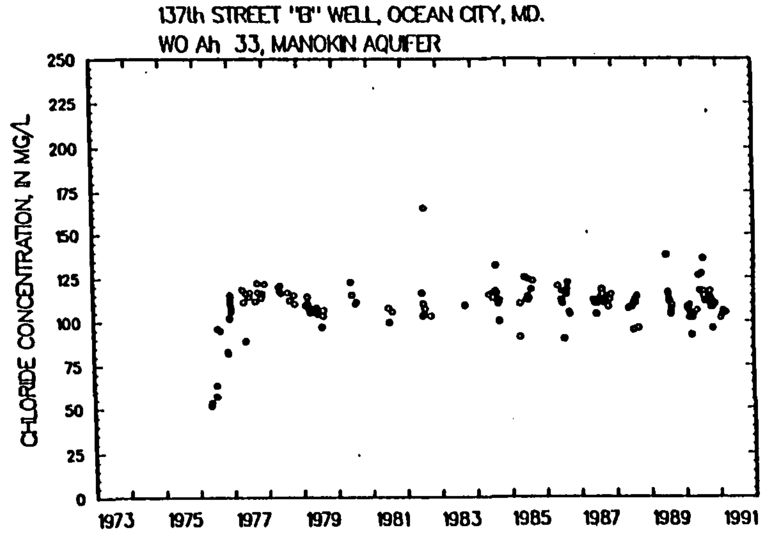
137th STREET "B" WELL, OCEAN CITY, MD.
WO Ah 33, MANOKIN AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
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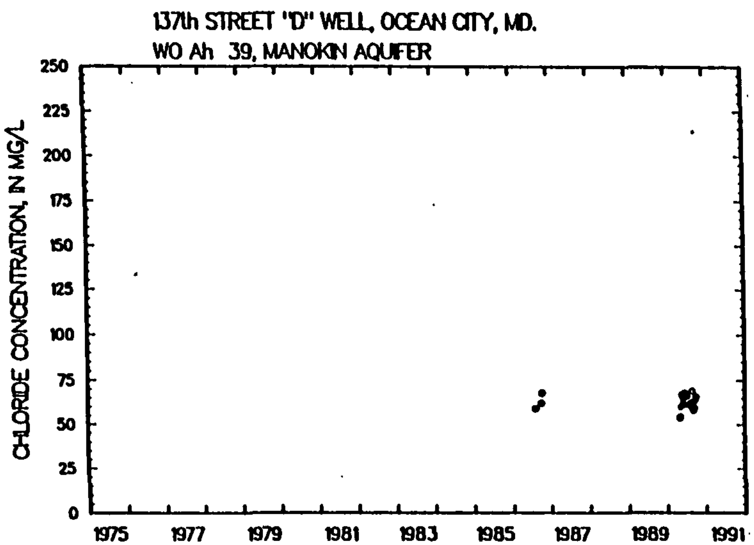
137th STREET "D" WELL, OCEAN CITY, MD.
WO Ah 39, MANOKIN AQUIFER
CHLORIDE CONCENTRATION, IN MG/L
0
25
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1975
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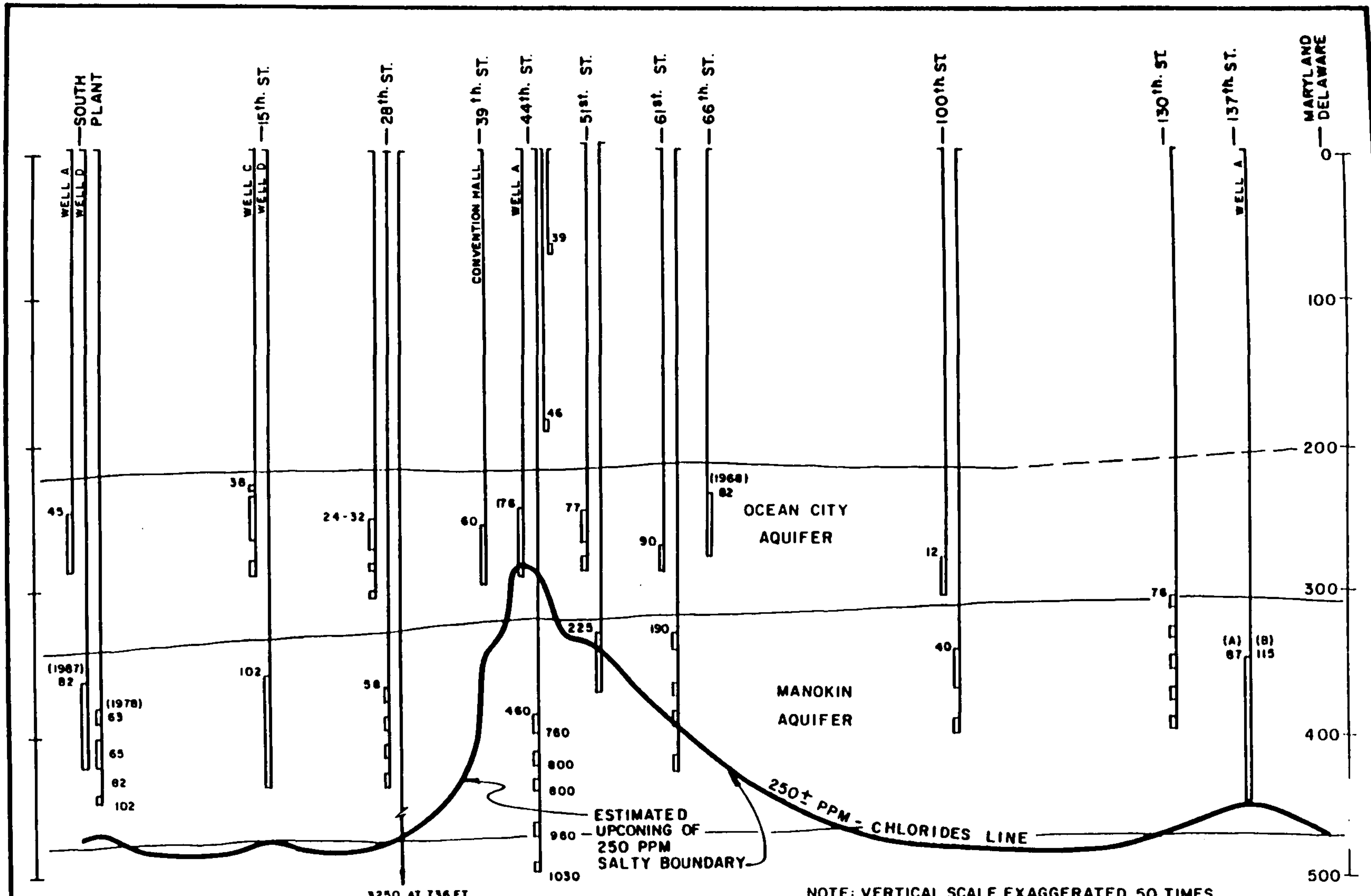
Figure 21E



WHITMAN, REQUARDT AND ASSOCIATES ENGINEERS	PROFILE AND CHLORIDES OBSERVATION AND PRODUCTION WELLS	TOWN OF OCEAN CITY MARYLAND
		DECEMBER 1991 FIGURE 22

Salt Water Intrusion Potential

The potential danger in the adequacy of the ground water supply to the Ocean City area is that excessive withdrawals from the aquifers will hasten salt water intrusion and make the aquifers unusable. The causes of salt water intrusion are manifold. The vicinity of the Atlantic Ocean and the Bay causes downward leakage into the aquifers as well as upward leakage from the underlying St.Mary's formation and other formations below, which are brackish. In addition the freshwater aquifers become salty beneath the Atlantic Ocean, and the freshwater/saltwater interface or saltwater wedge may move inland and affect the water supply of coastal communities. At present, the location of that saltwater wedge is not known [18]. Furthermore, the rate at which the wedge moves westward (inland) as a function of the rate of water withdrawal in Ocean City should be determined. DNR has recommended that off-shore test wells be drilled to determine the location and movement of the saltwater/freshwater wedge.

The 1992 MGS study [19] employed groundwater-flow models, article tracking in a steady-state flow model and mass balance calculations to estimate salt water encroachment at the 44th Street well field and the Gorman Avenue well field in 2010, for different pumping rates. The principal conclusions were as follows:

> "At the 44th Street well field, brackish water encroachment to the Ocean City aquifer occurs laterally and vertically... Simulated pumpage of 2.6, 3.3 and 4.4 mgd for 20 years from the Ocean City aquifer at the 44th street well field resulted in chloride concentrations of approximately 230, 235, and 243 mg/L in 2010; this simulation suggests the upper range of acceptable pumpage volume at the 44th Street well field.
>
> At the Gorman Avenue well field, brackish water intrusion to the Manokin aquifer occurs only as lateral encroachment... Simulating pumpage of 4.5 and 9.0 mgd from the Manokin aquifer at the Gorman Avenue well field resulted in chloride concentrations of approximately 170 and 185 mg/L."

Considering that the chloride water level in the Manokin wells is already currently elevated, the above data show the expectations of the water supply in the future to be marginal.

The 1990 DNR study [21], conducted jointly with the Delaware Department of Natural Resources and Environmental Control, centered on four related issues:

Issue #1: The potential exists for saltwater intrusion into the Pocomoke, Ocean City and Manokin aquifers at Ocean City.

Issue #2: The potential exists for saltwater intrusion into the Pleistocene aquifer near West Ocean City.

Issue #3: Water quality problems are widespread in wells in the Town of Fenwick Island, Delaware.

Issue #4: Potable water supply resources need to be planned for future development along the western shore of the Coastal Bays.

That reports provides the following short term principal recommendations:

Recovery period of the 44th Street well field should be increased during non-peak months.

"A" well at 44th Street should be placed in reserve as a "stand-by" well.

Chloride, pumpage and water levels should continue to be monitored.

Future wells should be spread out to reduce pumping stress.

The Town of Ocean City should develop a procedure for estimating future water demand that is independent of population projections.

Water conservation programs should be implemented, to include low water use plumbing fixtures, leak detection, and commercial incentives.

DNR, in cooperation with USGS should fund an off-shore drilling project to investigate location and movement of the saltwater wedge in the freshwater aquifer extending below the Atlantic Ocean.

Most of these measures are being implemented to varying degrees. DNR believes that these water management practices are sufficient to predict the saltwater intrusion into the Ocean City water supply to be unlikely.

On the other hand, **GSAC considers saltwater intrusion into the Ocean City/Sussex County water supply, even with the above measures, highly likely.** This judgment is based on consideration of the forecast growth of the region, the considerable uncertainties regarding the mechanisms by which saltwater intrusion is occurring, as well as the lack of key data, such as the location and movement of the saltwater wedge under the ocean,and the latest MGS data. However, given the lack of adequate data, the timing of the onset of prohibitive salination cannot be predicted at this time.

As a long-term measure DNR recommends that

> "The Worcester County Sanitary Commission, in conjunction with the WRA, should investigate the feasibility of inland well fields for a regional water supply."

The Corps of Engineer Study [41] performed engineering and economic analyses of alternatives to supplying water to that area. Four alternatives were considered:

(1) Surface water intakes using existing fresh water streams, specifically the Pocomoke River; the study also looked at using brackish water supplies which would require desalination plants;

(2) Drilling additional wells on the mainland, some distance away from the brackish and saltwater and

transporting the water to the current distribution system;

(3) Construction of an interconnecting network linking all existing water supplies to permit a more efficient pumping system; and

(4) Water conservation measures to reduce the projected water demands. This involves savings in the use of water as well as a pipeline leak repair program.

The Corps of Engineers provided comparative costs for installation and operations and maintenance for the following alternatives:

A surface water intake system using the Pocomoke

A surface water intake of brackish and saline water on the Isle of Wight and building a desalination plant in Ocean City

An inland well field to connect into the existing water distribution system in Ocean City

A inland well field with regional treatment plants to distribute to a regional system

Water conservation measures

The last alternative is not truly an independent alternative and probably should be pursued regardless of which other strategy is selected.

The comparative costs of the alternatives are shown in Table 10 [41]. The costs for the desalination plant are very approximate and appear high. On the other hand, total costs of the recent RO plant at ECI were not available. Furthermore, the cost of a single plant cannot be extrapolated to a much larger facility, using brackish water of different composition in a different environment. Also, the COE estimate is based on desalinating saline water at the Isle of Wight (chloride levels of 12-15,000 ppm) rather than desalinating brackish water from a deep aquifer (starting at 300 ppm and rising over the years to no more than (5000ppm).

The estimate for inland well fields uses unrealistically low cost assumptions, particularly with regard to the cost of land and easements needed.

The Town of Ocean City study [51] examined various desalination approaches, with emphasis on reverse osmosis (RO) and electrodialysis (ED) technologies. These membrane processes are

Table 10.

COST OF ALTERNATIVE WATER SUPPLY FOR OCEAN CITY
Corps of Engineers - 1985
($ Thousands - 1985)

	Pokomoke River		Isle of Wight		Inland Well Field Ocean City Treatment		Inland Well Field Regional Treatment	
Peak Supply (mgd)	10	16	10	15	10	15	10	15
Water Intake	27	32	110	135	1,420	2,440	1,420	2,440
Transmission Main	6,700	9,240	0	0	7,590	10,400	2,540	3,500
Pump Station	782	1,220	0	0	555	1,010	0	0
Water Treatment	6,218	8,690	20,324	29,775	?	1,353	3,827	5,331
Land	20	20	0	0	50	90	80	120
Total Investment	14,247	19,202	20,434	29,912	9,725	15,304	7,857	11,391

Notes: The cost of land acquisition is unrealistically low.

It is not evidernt why some trans,mission costs and pump station costs were omitted.

The cost of the desalination plant (Isle of Wight) is based on little and outdated evidence.

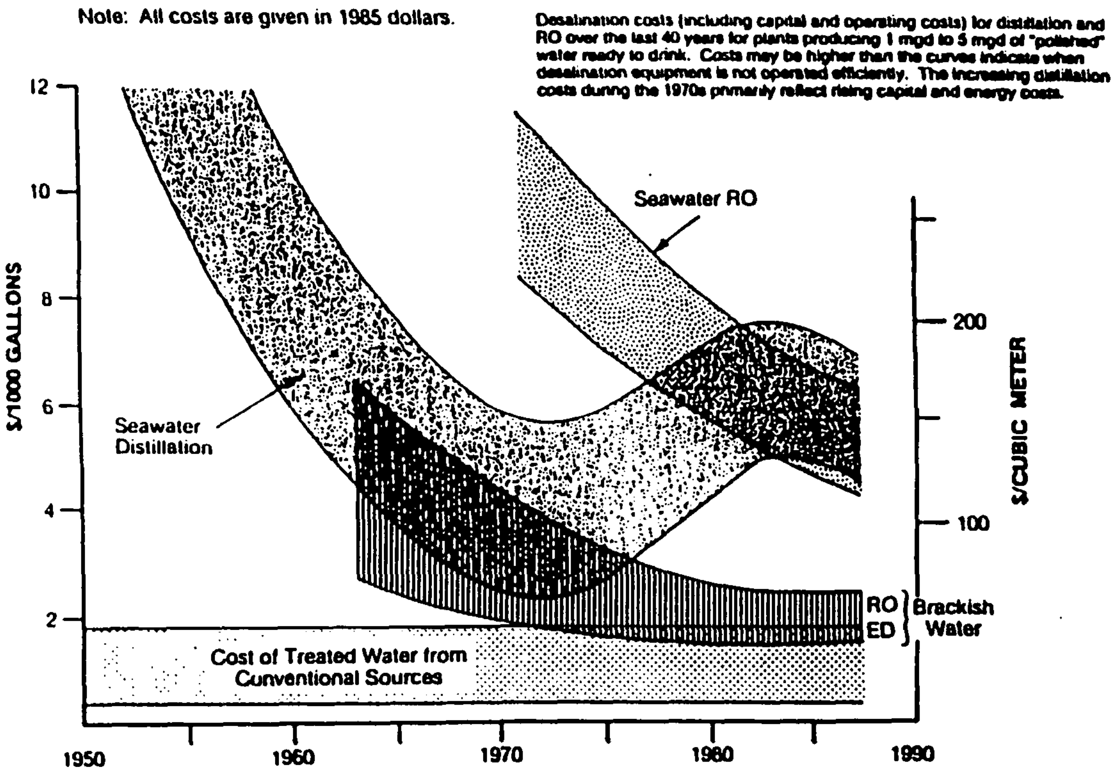
expected to be popular in the United States. While the system costs are highly variable depending on a number of key parameters, Figure 23 indicates that the cost of desalination of brackish water by RO or ED means is not much greater than the cost of treated water from conventional sources [51].

According to the cited reference salination equipment costs for the application with brackish water is from $ 0.60 to $1.25/-gpd permeate with capacities ranging from 1 to 10 mgd, and corresponding operating and maintenance costs of $ 0.50 to $ 1.50/1000 gal permeate [51].

Installation of desalination plants when and if needed are probably the most economic solution and that can be implemented in the least time. It also has least effect on the water supplies West of the Bay.

However, according to the Maryland Department of Natural Resources it is against State regulations to pump groundwater to the point at which it becomes brackish and then initiate desalination procedures. Furthermore, such a strategy would have direct impact on water quality in southeastern Sussex County in neighboring Delaware. Consequently, such a strategy would require consensus from both states. The existing Memorandum of Agreement (Appendix A) between Maryland and Delaware State agencies appears to be a vehicle for such discussions.

RANGE OF DESALTING COSTS
1959 - 1987



SOURCE: (BUROS 1989)

Figure 23.

Southeastern Sussex County, Delaware

The groundwater sources for Ocean City and those for the coastal areas of Sussex County are so connected that any impact on one supply also affects the other. Currently southeastern Sussex County relies almost entirely on individual domestic wells. Water withdrawn from Fenwick Island domestic wells has high iron concentration and elevated sodium concentrations from domestic iron treatment systems[21].

Thousands of individual wells are deep wells in the Chesapeake Group aquifers. Improperly constructed wells, or improperly sealed wells, as well as abandoned wells may act as conduit for contaminated water to reach lower, confined aquifers. This is particularly threatening along the barrier islands where the surficial aquifer contains salt water.

To facilitate growth in the area, to protect the groundwater resources and to insure long-term water supplies, the joint study [21] recommends that southeastern Sussex County combine into a regional water supply system. In planning for such a system the possible interconnection of water supplies of Ocean City and Fenwick Island must be addressed.

CONCLUSIONS

The GSAC has conducted an assessment of information pertinent to the evaluation of ground water resources, their quality and projected use in the Maryland portion of the Delmarva Peninsula - "Maryland's Eastern Shore". It has examined the overall status of groundwater in this region from the standpoint of present practice and problems in the agricultural and urban activity in central Delmarva.

DOE stated that, on the whole, the ground water supply to the Estern Shore appears to be satisfactory at this time. A vast majority of rural users can be expected to continue to use a safe and adequate water supply.

Current regulations in force through both the Wellhead Protection Program of the Water Management Administration (Department of Environment) and the Maryland Water Appropriation Act administered by the Water Resources Administration (Department of Natural Resources) have jurisdiction over water withdrawal practices and water quality monitoring which should, if conducted with diligence and adequate support, provide the data necessary for rational and timely decisions. With respect to the central Delmarva region, the GSAC has assumed that the Maryland programs under the departments cited above have, together with the USGS's NAWQA program, developed an adequate database from groundwater monitoring and regulation.

The GSAC noted that in the Salisbury area, which uses a relatively shallow water source, water protection regulations must be particularly diligently observed. Furthermore, it is noted that the presence of nearby water sources and the highly permeable paleo channel make Salisbury's water supply more vulnerable to contamination further afield than might typically be the case.

The GSAC perceives the main problem in groundwater supply to be that associated with saltwater intrusion into the coastal aquifers as a result of continually increasing water withdrawal to satisfy increasing demand related to new area development. In the Kent Island area intrusion of brackish water into the shallow aquifers supplying water to the island has already occurred.

A water management strategy was devised jointly by the Maryland Geological Survey (MGS), the Maryland Water Resources Administration (WRA), and Queen Anne's County to eliminate use of the Aquia aquifer and use the deeper Magothy aquifer instead. The implementation of this plan appeared to have stabilized the saltwater intrusion problem, according to the latest MGS reports.

In considering this major concern of Maryland's Eastern Shore population, the recommendations for amelioration of brackish water encroachment and the implementation of remedial measures may affect residents far inland from the site of the immediate problem, particularly in the Ocean City area.

The most serious threat of saltwater intrusion is believed to occur in the Ocean City/Worcester County, Sussex County area, where also the greatest economic development and population growth have been forecast.

DNR has recommended a number of short term water management practices, that are already being implemented to varying degree. DNR believes these practices will be sufficient to make excessive saltwater intrusion into the Ocean City water supply unlikely.

DNR believes that these water management practices are sufficient to predict the saltwater intrusion into the Ocean City water supply to be unlikely.

On the other hand, **GSAC considers saltwater intrusion into the Ocean City/Sussex County water supply, even with the above measures, highly likely.** This judgment is based on consideration of the forecast growth of the region, the considerable uncertainties regarding the mechanisms by which saltwater intrusion is occurring, as well as the lack of key data, such as the location and movement of the saltwater wedge under the ocean,and the latest MGS data. However, given the lack of adequate data the timing of the onset of prohibitive salination cannot be predicted at this time.

Furthermore, the aquifers serving Ocean City, the areas west of Assawoman and Sinepuxent Bay, as well as the coastal areas in Delaware are so interconnected that they operate almost as a single hydrological system. It is, therefore, essential that any plan be integrated with an overall plan for the whole region, to include all jurisdiction which would be affected by Ocean City's water withdrawal plans. Solutions must, therefore, be based on multi-state approaches, with appropriate interagency coordination. A Memorandum of Agreement between Maryland and Delaware agencies already exists to serve as a vehicle for joint planning.

Well before salt-water intrusion actually occurs, a decision is required between three courses of action in order for the long range, advanced planning to proceed:

- Development of a supplementary well field inland with raw water being supplied to the Ocean City treatment facilities for distribution, probably including the Fenwick Island region

- Development of a supplementary well field inland with local treatment facilities and distribution of treated water to Ocean City distribution facilities and to the Western Shore areas, as well as to Fenwick Island.

- Desalination of brackish water at Ocean City, which would probably also require distribution of pure water to Fenwick Island and related communities.

Inland well-fields take a very long time to survey, plan, design and construct. Land acquisitions and easements can be costly and time consuming. In terms of capital expenditure and upkeep these alternatives are very costly. The very detailed plan developed by Ocean City to rely on desalination of water from deeper, brackish aquifers appears to be less expensive, in the long run and easier to implement. However, DNR observes that this particular strategy is currently against State Regulations.

The inland wellfield strategy should be examined to determine

(a) if the confined aquifers can support the stress of the large amount of withdrawals required to supplement the water supply of Ocean City, without causing saltwater intrusion in those aquifers, and

(b) if this strategy is economically feasible on the basis of a comprehensive economic analysis of all the resources required.

Given the uncertainty regarding when saltwater mixing becomes prohibitive, and the time necessary to implement the DNR preferred alternative, desalination may have to be chosen by default.

GSAC emphasizes that the problem of supplying adequate pure water resources to Ocean City, the western shore of the Bay and southern Sussex County, Delaware is very complex and must involve developing a master plan, involving <u>all</u> the jurisdictions involved, and weighing all alternatives objectively.

Finally, it must be observed that water resources on the Eastern Shore are finite. Also, many of the aquifers in the area have water recharge areas that are far removed from where the water is actually withdrawn. It is, therefore, essential that an overall regional plan be developed in which the needs "down stream" be considered before large scale developments, impacting these recharge areas, are approved. Furthermore, this plan should consider the latest water resource data and usage data, as well as consideration of future growth and land use.

RECOMMENDATIONS

Strict management of the water resources for Salisbury, including the recharge areas, must be maintained.

The decline in the water level of the Piney Point aquifer in Caroline County and environs should be carefully monitored and further withdrawals of this aquifer should be restricted accordingly. Contingency plans should be prepared before previous wells run dry.

The impact on the Magothy water level, as a result of the implementation of the Kent Island water management strategy should be carefully monitored.

The general application of the 80% water level policy to determine adequacy of the water supply should be reexamined to assure that previous updip well owners are not impacted, and that the drawdown is not sufficient to cause saltwater intrusion.

The feasibility of using inland wellfields to supplement the Ocean City water supply must be carefully studied in order to prevent upsetting the balance between existing aquifers and the intrusion of salt water into the water supply west of Assawoman Bay.

A full economic analysis should be performed of all the resources required for an inland wellfield strategy to supplement the water supply of Ocean City, and possibly southern Sussex County, Delaware to determine the economic feasibility of such a strategy.

The selection of a strategy to solve the Ocean City, Sussex County water supply is very complex and involves several jurisdictions. It is essential that a master plan be developed in conjunction with all the jurisdiction involved, and that all alternatives be examined.

If desalination is the selected alternative, agreements should be made between the affected states, and the restricting State Regulations changed accordingly.

It is essential that an overall regional plan be developed in which the needs "down stream" be considered before large scale developments, impacting these recharge areas, are approved. Furthermore, this plan should consider the latest water resource data and usage data, as well as consideration of future growth and land use.

EASTERN SHORE WATER PROJECT

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ABBREVIATIONS

DNR	Maryland Department of Natural Resources
DOE	Maryland Department of the Environment
ECI	Eastern Correctional Institution
EPA	E.S. Environmental Protection Agency
gpd	Gallons water per day
GSAC	Governor's Science Advisory Council
mgd	Millions gallons of water per day
mg/l	Milligram per liter
MCL	Maximum contaminant level
MGS	Maryland Geological Survey
NAWQA	National Water-Quality Assessment Program
pH	Acidity Level
SMCL	Secondary maximum contaminant level
USGS	U. S. Geological Survey
WHPA	Wellhead Protection Area
WHPP	Maryland Wellhead Protection Program

Maryland Department of Natural Resources

Water Resources Administration
Tawes State Office Building
Annapolis, Maryland 21401
Telephone: (301) 974-3675

William Donald Schaefer
Governor

Torrey C. Brown, M.D.
Secretary

Catherine P. Stevenson
Director

KENT ISLAND WATER MANAGEMENT STRATEGY

No new water appropriations will be approved for the Aquia aquifer beneath Kent Island. For the portion of Queen Anne's County east of Kent Narrows and west of Queenstown Creek and the Wye River, no new water appropriations over 1,000 gpd will be approved from the Aquia aquifer.

For the area east of the Wye River and including substantial portions of Queen Anne's and Talbot counties and the Easton and St. Michaels areas as indicated below, large Aquia aquifer appropriation requests will be strictly scrutinized with respect to their potential for contribution to the saltwater intrusion problem. This area is described as follows:

Beginning in the Chester River immediately north of the mouth of Queenstown Creek, the boundary of this area proceeds clockwise in the following manner: up the Chester River to the Corsica River, then up the Corsica River and Yellow Bank Stream to the Centreville town limits, then easterly, southerly, and westerly along the Town limits to MD Route 213, such that all of Centreville is within this area. From Centreville, it continues south along MD Route 213 to the junction with US Route 50. It then follows US Route 50 south to its bridge across Peachblossom Creek, south of Easton. After following Peachblossom Creek west to its confluence with the Tred Avon River, it proceeds southwestward into the Chesapeake Bay, and turns northward, west of Tilghman Island. Trending northeastward, it enters Eastern Bay, and enters the Wye River just west of the Wye Institute. It continues northward along the Wye River, then crosses U.S. Route 50 immediately west of Queenstown, and follows Queenstown Creek back to the Chester River.

Applicants proposing projects which have an adverse impact on the Aquia aquifer will be required to revise the application to mitigate the impact.

MEMORANDUM OF AGREEMENT
BETWEEN
THE MARYLAND WATER RESOURCES ADMINISTRATION
AND
THE DELAWARE DIVISION OF ENVIRONMENTAL CONTROL
CONCERNING THE
PROTECTION, CONSERVATION, DEVELOPMENT, AND MANAGEMENT
OF GROUNDWATER RESOURCES FOR MUTUAL BENEFIT

WHEREAS, the Maryland Department of Natural Resources, Water Resources Administration has the responsibility for planning, managing and supervising the development, utilization, conservation and protection of the groundwater resources of the State of Maryland; and

WHEREAS, the Delaware Department of Natural Resources and Environmental Control, Division of Environmental Control has the responsibility for planning, managing and supervising the development, utilization, conservation and protection of the groundwater resources of the State of Delaware; and

WHEREAS, increasing demands for groundwater to be supplied from aquifers common to both states on the Delmarva Peninsula have had or are expected to have impacts across the State line; and

WHEREAS, a continuity of open and good faith discussion of problems and opportunities that are mutual to both states is considered necessary for proper groundwater resources management; and

WHEREAS, there are important items of mutual concern that should be addressed and resolved in certain groundwater programs and activities, including, but not limited to:

1. Action to resolve groundwater interference problems arising from development of aquifers common to both states;
2. Sharing of groundwater withdrawal records and groundwater level records;
3. Evaluation of groundwater withdrawal proposals in excess of 100,000 gallons per day or those having potential impact on water levels across the states' boundary; and

4. Planning for water supply in regions contiguous to or near the boundary between the two states.

NOW, THEREFORE, it is agreed between the Maryland Water Resources Administration and the Delaware Division of Environmental Control that continuing discussions will be held and groundwater data will be shared between their designated representatives; the objectives of which shall be to develop and establish:

1. Arrangements for cooperation on and resolution of groundwater resources matters that are of mutual interest to the states; and,
2. Joint positions on issues, questions, and proposals in the area of groundwater resources management that are of significant interest to both states; and
3. A joint approach to the equitable sharing of groundwater resources common to both states.

IN WITNESS THEREOF, the Director of the Maryland Water Resources Administration and the Director of the Delaware Division of Environmental Control agree and sign this 8th day of October, 1982.

State of Maryland
Department of Natural Resources
Water Resources Administration

Witness

by: (seal)
Thomas C. Andrews, Director

State of Delaware
Department of Natural Resources and Environmental Control
Division ~~of Environmental~~ Control

Witness

by: (seal)
Thomas P. Eichler, Director